Keeping Fire: The Cognitive Implications of Controlled Fire
Use by Middle Pleistocene Humans

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Abstract

The thesis investigates the cognitive implications of controlled fire use by Middle Pleistocene humans. My argument is that we can infer features of human cognition from the behaviours required to control fire. This argument is grounded in the following two premises.

First, some behaviours imply the operation of distinctively human cognitive abilities. For example, inhibiting prepotent responses, delaying gratification and anticipatory planning provide good evidence for executive functions, such as episodic memory, an extended working memory capacity and detached representations. Similarly, future directed cooperation, resolving social dilemmas and providing a public good imply features of human social cognition, such as theory of mind, collective intentionality and intersubjective communication.

Second, fire use involved a range of cognitively demanding behaviours associated with accessing, maintaining and using fire that I argue meet the above behavioural criteria for human cognitive abilities. The thesis aims to show why this is the case.

My working hypothesis is that fire related tasks stand as a sound behavioural basis for making inferences about the cognitive abilities of fire using humans. The thesis is warranted because we now have compelling evidence that humans have been using fire for at least 800 thousand years. The cognitive abilities of humans from this early time are not well understood and in dispute. The thesis is pertinent because it has high potential to provide new information about the timing and context in which important human cognitive abilities evolved.
Declaration

(i) The thesis comprises only my original work towards the PhD.

(ii) Due acknowledgement has been made in the text to all other material used.

(iii) The thesis is less than 100,000 words in length, excluding tables, maps, bibliographies and appendices.

Terrence Twomey
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The encouragement of Dr Douglas Lewis is appreciated. His assistance throughout my candidature was helpful. Dr Neil Thomason has helped me to think and write with some clarity. Without him the thesis would make far less sense. His support in developing and organising the thesis throughout my candidature, and in submitting the final draft, is valued and appreciated. The thesis would not have been possible without the help of Prof Antonio Sagona. He has assisted me greatly where my archaeological knowledge was limited and has encouraged my ideas from their inception. For this, and his help preparing and correcting final drafts, I am greatly indebted. Thanks to Prof Andrew Dawson for supervising the final stages and submission of the thesis. The work, support, time and efforts of all my supervisory committee throughout my candidature and in producing the final product are greatly appreciated.

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Chapter One: Introduction

1.1 Introduction

My thesis is that we can infer features of human cognition from evidence for controlled fire use. I will argue that competent fire use by early humans involved a complex of cognitively demanding behaviours associated with accessing, maintaining and using fire. From the practical constraints of Middle Pleistocene fire use, I will argue that successfully engaging in fire related behaviours required a suite of distinctively human cognitive abilities.¹ My reason for focusing on the Middle Pleistocene rather than culturally or technologically derived chronologies is that the earliest clear evidence for fire use dates to the beginning of the Middle Pleistocene, and fire use is a common human behaviour by the end of this period. The central claim of the thesis is that we can infer response inhibition, anticipatory planning, delayed consumption, future directed group cooperation and providing a public good from the fact that Middle Pleistocene humans solved fire related problems. These behaviours provide good evidence for extended working memory capacity, episodic memory, theory of mind, collective intentionality and intersubjective communication.


¹ The Pleistocene Epoch extends from 1.806 million years ago (mya) to 11.42 thousand years ago (kya) incorporating the Early Pleistocene from 1.806 mya to 781 kya, the Middle Pleistocene from 781 kya to 126 kya and the Late Pleistocene from 129 kya to 11.42 kya. This information is endorsed by the International Commission on Stratigraphy (ICS). https://engineering.purdue.edu/Stratigraphy/resources/geowhen/Pleistocene.html Accessed 18/10/2010. The standard abbreviations ‘kya’ and ‘mya’ are used in reference to thousand years ago and million years ago respectively.
Direct archaeological evidence from Gesher Benot Ya’aqov in Israel (Alperson-Afil & Goren-Inbar 2010) and indirect evidence for cooking (Wrangham 2009) places fire using societies at around 800 kya. This makes fire use important because our knowledge of human cognition derived from other lines of evidence from this time is limited. In general, our efforts to infer the cognitive capacities of early humans from paleoanthropological evidence have not been overly successful (Clark 2002: 50). Fire use provides a sound behavioural basis for making inferences about early human cognition that is yet to be investigated. However, all paleoanthropological research into cognition is speculative to some extent. My argument is based on reasonable speculations that are justified in the main body of the thesis. As these are central to my argument I will state and briefly qualify these premises.

1.1.1 Key Premises and Conditions

Fire users of the Middle Pleistocene depended on fire to survive. We do not know when populations of humans started to become dependent on fire. However, several lines of evidence support the claim that Middle Pleistocene humans were obligate fire users.\(^2\) There is direct evidence for controlled fire use dating to around 800-700 kya and more widespread fire use from about 400 kya onwards. Both the Neanderthals and *Homo sapiens* living at the end of the Middle Pleistocene were evidently obligate fire users (Klein 1999: 238) and probably inherited the behavior from a common ancestor. The cooking hypothesis, discussed in Chapter Two, suggests humans of the Middle Pleistocene would have struggled to meet their daily energy requirements on a diet of raw food only. It is unlikely that the increase in relative brain size that occurs in human populations between about 750-200 kya (Calvin 2004: 45-50) could have occurred without regularly eating cooked foods. Many Middle Pleistocene humans lived in seasonally or permanently cold climates where fire would have been required to keep warm.

\(^2\) Early Pleistocene humans are less likely to have depended on fire because their metabolic demands were less, and they do not appear to have occupied cold environments as discussed in Chapter Four below.
Fire users of the Middle Pleistocene could not make fire. We do not know if Middle Pleistocene humans could make fire or not. There is no evidence that they could and circumstantial evidence to suggest they could not. However, we cannot be sure. This is a problem because the behavioural and economic implications are different for people who cannot make fire from those who can. My approach here is to argue that fire making is at least as cognitively demanding as fire use in the absence of ignition technologies. It is also reasonable to think a period of controlled fire use preceded the invention and diffusion of fire making, although both may have occurred prior to the Middle Pleistocene. While I will consider the cognitive implications of fire making, I will work mainly from the premise that Middle Pleistocene humans were competent fire users, but not fire makers.

Fire users could not rely on natural fires to access fire if their fire went out. The literature on early human fire use does not critically consider how often fire users were likely to encounter natural fires. Most natural sources of fire are rare. The return times for naturally occurring grass and forest fires are measured in years, decades and centuries. In some places where Middle Pleistocene humans lived, such as the boreal forests and the temperate grasslands of Northern Europe and Asia, natural fires would have been very infrequent. If we take the return times of naturally occurring fires as a proxy for how often Middle Pleistocene humans in a given environment encountered natural fires, then most Middle Pleistocene humans could not have relied on these to regain fire if their fire went out.

Fire use is a relatively costly behaviour in terms of time, energy and risk. Fire users of the Middle Pleistocene did not have access to high quality fuel and would have predominantly used dry deadwood that could be picked up as they moved around. Fire users would quickly have used up the dry deadwood close to a domestic fire. Many fire users lived in environments with open grassland, uneven terrain, seasonal snow cover, or with very hot or very cold climates. In these conditions fuel would have been scarce, difficult to gather or both. Fire users could have spent similar amounts of time and energy sustaining a fire as they did on foraging, socializing, making stone
tools and caring for the young. Fire use may also have involved risks associated with fire related tasks and obligations. All things considered, the day-to-day maintenance of fire involved costs comparable to other activities.

Early humans used the least cognitively demanding behaviours that would have sufficed to solve fire related problem. Middle Pleistocene fire users must have used at least the simplest strategies that allowed them to be fire users. We know this because controlled fire use could not have evolved otherwise. We also know that whatever strategy Middle Pleistocene humans used, it had to work in a range of different environmental contexts. Although we cannot know exactly how Middle Pleistocene humans solved fire related problems, the simplest sufficient strategies can stand as a basis for making inferences about behaviour and cognition, because fire users must have adopted these, or more cognitively demanding behaviours. For example, if day-to-day fuel gathering was sufficient, then we need not infer that Middle Pleistocene humans stockpiled fuel. However, if day-to-day fuel gathering was too inefficient or ineffective in some contexts, then we can infer that fire users in these circumstances stockpiled, or adopted some other solution.

1.1.2 The Problem

My thesis addresses the broader multidisciplinary problem of explaining how human cognition evolved. With respect to language and higher-order consciousness that seem to make human cognition qualitatively different from that of other animals, this is considered to be one of the hardest problems in science (Christiansen & Kirby 2003: 14-15, Chalmers 1995 passim). The scarcity of archaeologically evident behaviours from which we can infer cognitive processes compounds the problem. Human cognition is evidently different from that of other animals. As such, we are trying to explain how and when the cognitive differences evolved that distinguish

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3 Higher-order consciousness refers to the capacity to be conscious of being conscious. In humans with linguistic abilities higher-order consciousness enables a social concept of the self and concepts of past and present. It can be distinguished from primary consciousness that enables the construction of a scene in the remembered present without any sense of past or future. While birds and mammals experience primary consciousness they most probably lack the sense of a self in time associated with higher order consciousness (Edelman 2004 passim).
humans today from other animals. How did our ancestors come to interpret, communicate and contemplate information in the way humans do today?

I believe an investigation into the cognitive implications of controlled fire use can help us better understand many issues associated with the evolution of cognition. For example, why do humans cooperate, how and when did protolanguage and language evolve, how and when did human culture evolve, in what contexts would executive functions and higher-order consciousness have been adaptive and how did human social cognition evolve? Fire use can help us answer these questions because controlled fire use established a behavioural niche in which future directed self-regulation, episodic memory, extended working memory capacity, human modes of cooperation and intersubjective communication would have been highly adaptive if not required. I suggest that fire use has high potential to help us investigate these questions.

1.2 Aims of the Thesis

My thesis aims first to provide a detailed analysis of the behavioural requirements for controlled fire use relative to the constraints facing Middle Pleistocene humans. In particular, the constraints associated with their forager lifestyle, habitat, climate, demography, and resource availability. Second, it aims to identify the cognitive abilities that allowed fire users to meet these requirements. Third, it aims to present an argument for why these abilities would have been required, or adaptive, in the context of fire use. Fourth, it aims to contribute to, and improve, our understanding of early human cognition, and the contexts in which human cognition evolved. Finally, the thesis aims to contribute to the broader multidisciplinary aim of explaining human cognitive evolution by providing a ‘bridging’ or ‘middle range’ model of early human cognition that connects the cognition of an apelike ancestor to that of humans with modern cognitive abilities.

By focusing on these issues I aim to provide a set of heuristics for thinking about the cognitive abilities that were required to control fire. Scholars of prehistory have not considered in any systematic way the
cognitive demands associated with domesticating fire, nor the kinds of problems Middle Pleistocene fire users had to solve, and the kinds of conditions that made controlling fire more or less difficult. How did early humans develop and maintain a technology that was, arguably, comparable to much later technologies such as the invention of the wheel (Ofek 2001: 3)? This thesis will provide a basis for investigating these issues and for testing the premises supporting the main argument of the thesis.

1.3 Significance of the Research

My investigation is warranted because the cognitive abilities of Middle Pleistocene humans are not well understood. To date research into the probable relationship between the evolution of human cognition and fire use has been limited, even though fire use is considered an important behavioural adaptation in this respect (Peris 2010: 10, Wrangham & Carmody 2010: 197, Wrangham 2009: 105-106, Burton 2009: 29-30, Karkanas 2007: 197, Gowlett 2006: 299, Darwin 2006 (1871): 855, James 1989: 1, Clark & Harris 1985: 3, Ofek 2001: 3). An investigation into the possible relationship between fire use and cognition is important because evidence for fire use establishes a sound empirical basis for making inferences about cognition, from a time when our understanding of human cognition is limited.

Inferring cognition from evidence removed from us by hundreds of thousands of years is difficult. Evidence for cognitively demanding behaviour is scarce and evidence is often ambivalent with respect to cognitive abilities. Fire use was arguably a cognitively demanding behaviour relative to the evident foraging behaviours and lithic technologies of Middle Pleistocene humans. Claims for fire use by Middle Pleistocene humans are treated with due skepticism (James 1989). However, we can now be reasonably sure humans have been using fire from at least 800 thousand years ago, and keeping fire is arguably the most complex behavioural adaptation we know of from this early period. This being the case, an investigation into the cognitive requirements of fire use could provide new information about how and when important features of human cognition evolved.
1.4 Approach

1.4.1 Inferring Cognition from Prehistoric Behaviour

We do not have direct evidence for prehistoric cognitive processes. In the case of early humans, we must infer behavioural patterns from the available material, and from these, the minimum cognitive abilities needed to produce inferred behaviours (Bednarik [Wynn] 2003: 120-121). I will follow Coolidge and Wynn’s approach to identifying cognitive capacities from archaeological evidence, which involves identifying evidence for behaviours that could not have been conducted without human cognitive abilities (2007: 81). Wynn recommends that “An argument in cognitive archaeology must invariably be based on a sequence of inferences, each of which must be explicit and persuasive if the argument as a whole is to be credible” (Wynn 2009: 9544).

Thus, from an artifact or feature, such as controlled fire use, we infer technical or social systems, from which we infer procedures and knowledge, from which we infer the minimum necessary cognitive requirements (Wynn 2009: 9544). Botha refers to this approach more broadly as ‘the windows approach’ (Botha 2006: 129). Some phenomena, not necessarily archaeological data, may provide metaphoric ‘windows’ on the evolution of human cognitive abilities like language, for which we lack direct evidence (Botha 2006: 129). Ronen (1998) and Gouldsblom (1989) have both argued that domestic fire provides a window on language evolution in this sense. The windows approach refers to both the above argument structure, and a means of evaluating the reliability of ‘windows’ that have been proposed in terms of grounds, warrants and pertinence (Botha 2006: 129).

This approach assumes that engaging in some behaviour requires a minimum degree of cognitive competence, and that some behaviour is more cognitively demanding than others. If we can say why a particular behaviour is cognitively demanding or why it is more demanding than another, then differences in behaviour may reflect underlying differences in cognitive abilities. This reasoning informs most research into the origin of human cognition.
Psychologists tend to interpret behaviour parsimoniously (Smith 2009: 390). If a simple explanation will do then we need not evoke higher order cognitive functions. Paleoanthropologists should adopt a similar approach when inferring cognition from evidence, by focusing on the minimum necessary cognitive competence required (Bednarik [Wynn] 2003: 120-121). If classical or operant conditioning can explain behaviour, then we are not entitled to infer more complex cognitive processes involving executive functions or collective intentions. Although this means we may underestimate the cognitive capacities of early humans, it prevents us from speculating beyond what the evidence can tell us.

The general consensus is that most non-human animal behaviours can be explained in terms of adaptive innate, or learned, stimulus-response associations that have been reinforced over time. Reinforcement catalyzes stimulus-responses associations and stimulus cues elicit behavioural reactions (Smith 2009: 393). This is not to say animals cannot solve novel problems or lack complex cognitive systems. However most, if not all, animal behaviour is bound to some direct somatic, iconic or indexical referent that motivates and initiates the cognitive processes and representations needed to produce the behaviour (Deacon 1997 passim). Middle Pleistocene human behaviour is often interpreted this way (Nobel & Davidson 1996, Jordan 1999, Tattersall 2002, Lewis-Williams 2004. See Rosanno 2009, Barnard et al. 2007, Donald 2001, and Hallos 2006 for an alternative view. See Shreeve 1995 for a full review of the key issues concerning the modern human behaviour debate).

To avoid undue speculation, I will assume that fire users adopted the simplest strategies that could have worked, because these are more likely to represent the minimum cognitive competence needed to keep a fire. While fire users may have adopted more complex behaviours, they must have adopted the least cognitively complex behaviours that sufficed. I will also argue that in most situations, but not necessarily all, optimal strategies would have been more cognitively demanding.
Inferring cognition from prehistoric human behaviour is difficult because evidence is scarce and often ambivalent with respect to cognition, and because cognition is difficult to define and model in general. Behavioural criteria that unambiguously identify the cognitive processes in question are difficult to establish. My main concern is establishing behavioural criteria that are applicable to fire related behaviours. This is not easy because despite a general consensus as to what cognition involves, there is no consensus as to the best way to define or model neuropsychological processes in humans or animals (Ardilo 2008: 94, Aunger & Curtis 2008: 318, Jurado & Rosselli 2007: 213, Scott-Phillips 2007: 387, Fisher 2006: 291, Gershenson 2004: 151, Barkley 2001: 2, Botha 2000: 150, Kamil 1998: 4). This is because we do not fully understand how the brain gives rise to the neuropsychological mechanisms that govern cognition. Competing theoretical perspectives are well suited to describing cognition in some contexts, but none are well suited to explaining all aspects of cognition (Gershenson 2004: 135). Also, socially and historically derived biases tend to cloud research into the cognitive differences between animals, early humans and us (Corby 2005 *passim*, Murray 2001 *passim*, Clark 2001 *passim*).4

A further difficulty in establishing behavioural criteria for human cognitive functions is that they are not usually analysed in the natural ecological conditions of day-to-day problem solving (Ardilo 2008: 93, Barkley 2001: 24). Many of the tests used in cognitive psychology are simply not relevant to the issue of early human behaviour. We cannot subject Middle Pleistocene humans to false belief tests (Coolidge & Wynn 2009: 201). Also, when testing human subjects, experimenters presume human cognitive competences, such as language, that I am not entitled to presume were operational. I will therefore focus on behavioural criteria that provide good evidence for human cognitive processes such as future directed self-regulation and human modes of cooperation. My approach relates fire use to the behavioural criteria that identify important aspects of human executive functions and social cognition.

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4 For a review of the often implicit historical and social biases associated with paleoanthropological research see Corby & Rebroeks 2001, and Corby 2005.
1.4.2 A Three-Stage Model for the Origin of Fire Use

Scholars have suggested probable stages in the evolution of fire use, from the opportunistic use of natural fires, to total control over fire involving the ability to make fire at will (Burton 2009: 43, Rolland 2006: 249-250, Ronen 1998: 443, Frazer 1930: 201). The idea that fire users went through a period when they could control fire and probably needed fire to survive, but could not make fire at will, is important to my thesis. Frazer notes (1930: 201) that myths for the origin of fire use, "...implicitly assume three successive ages, which we may call the Fireless Age, the Age of Fire Used, and the Age of Fire Kindled. However these conclusions may have been reached, whether by speculation or by actual reminiscence orally transmitted, it seems highly probable that they are substantially correct."

The ‘age of fire used’ can be further divided into two stages: passive and active. At some point early hominins began interacting with fire for whatever reason, becoming increasingly familiar with its properties and benefits (Gouldsblom 1986: 518-519, Burton 2009: 19-43). We can call this the ‘passive stage’. In the ‘active stage’ some of these hominins became increasingly competent at keeping a fire going, and as a result become increasingly dependent on fire’s benefits. Increasing control was likely intended, while increasing dependence was not (Goudsblom 1992a: 6). Eventually some of these hominins invented ignition technologies heralding ‘the age of fire kindled’ (Gouldsblom 1986: 520-521, Burton 2009: 19-43).

By excluding Frazer’s ‘fireless age’, and dividing ‘the age of fire used’ into ‘passive’ and ‘active’ stages we can propose a three-stage model along the following lines. In the first stage a hominin ancestor is using fire passively, by associating fire with some benefit, or benefits, and using fire opportunistically to exploit the potential benefit (Burton 2009: 34-41). In the second stage our ancestors are able to control fire in that they can sustain a fire for long durations. Throughout the thesis I am using the term fire users in reference to this hypothetical group. In the third stage humans can make fire at will. As with other major human ecological and social transitions we can
assume a) there was once a time when no human groups controlled fire, b) there was once a time when there were both groups with and groups without fire, and c) we have now reached a time when there are only groups with fire (Goudsblom et al. 1996: 24).

I am concerned with hominins who could control fire and were largely dependent on the benefits of fire to survive, but who could not yet make fire. Although, this scenario is hypothetical it is reasonable to think humans went through these kinds of phases as we increasingly gained mastery over fire and became increasingly dependent on it (Ronen 1998: 443). Following Goudsblom et al. (1996: 21-24) we can also note that passive fire users once existed at the same time as active fire users, and active fire users existed with those who could make fire. In Chapter Five I will offer reasons why it is likely humans once existed who depended on fire but could not make it at will. This is a key premise of the thesis. However, I will also discuss the cognitive implications for fire makers in contrast to active fire users.

1.5 Perspective and Focus

I will adopt an evolutionary perspective, assuming that cognition has evolved through a process of natural selection and is subject to the principles governing that process (Lewontin 1998: 109). The principles include:

1. *The principle of variation.* There is variation of physiology, anatomy, and behavior among individual members of a species.

2. *The principle of heredity.* Offspring resemble their parents in their traits more than they resemble unrelated individuals. This similarity is usually a consequence of biological inheritance of genes, but it need not be. Mechanisms of cultural inheritance that cause persistent correlation between parents and offspring over successive generations would also provide the needed heredity for the evolutionary process.

3. *The principle of natural selection.* Individuals with some traits leave more offspring than others, because the possession of those traits makes them more able to acquire the necessities of life in the struggle for existence and reproduction.
Fire use can be considered a behavioural trait that may have been subject to these principles. At some point in our biological history hominins probably varied in their capacity to control fire. Fire use would have been culturally heritable. Individuals in possession of this behavioural trait would have been better able to meet their survival and reproductive needs than those without. We may lack the demographic and genetic information to propose testable hypotheses for the evolution of cognition (Lewontin 1998 *passim*). However, if possession of a cognitive trait was required to control fire, cognitive traits are heritable and controlling fire was adaptive, then a cognitive trait that supports fire use could have been subject to selection. Thus, it is reasonable to think behaviours requiring complex cognitive abilities may be implicated in the evolution of those abilities, as they exist in modern humans today.

When considering the evolution of complex behavioural and cultural phenomena, and the complex cognitive processes that support them, we need to consider these systems in a developmental context, in particular when considering human culture. Sterelny emphasizes (2008: 2) four factors structuring human cognitive evolution that are not at odds with the standard evolutionary principles.

1. Cultural inheritance: we have complex cognitive adaptations – for example, the natural history competences of foragers – that are built by cumulative selection on culturally transmitted variation.
2. We are adapted for cultural learning: for example joint attention is a key adaptation underpinning human cultural learning allowing individuals to monitor, and learn from, the social and technical activities of others.
3. Human cognition is plastic: very different phenotypes emerge from the interaction between environments and inherited resources.
4. We develop in structured learning environments: the culturally mediated flow of information across the generations is reliable and of high fidelity. This reliability and fidelity depends on the fact that we construct the evolutionary niche of the next generation.
While my argument is dependent on evolutionary principles, it is not an argument for the evolution of human cognition in its current state. However, I will argue that the cognitive abilities implicated in fire use would have served as a basis from which more complex cognitive processes could have evolved, and would have facilitated their development in individuals. A theme of my argument is that at some point in our evolutionary history, our ancestors began to inhabit a fire using niche, and this changed the course of human evolution in unprecedented ways with respect to cognition.

Cognitive abilities and differences can be better appreciated if we consider the problem solving context in which they evolved (Barkley 2001 *passim*). I am focusing on cognitive abilities that would have been adaptive in solving fire related problems. In particular, the problems associated with accessing, transporting, maintaining and using fire. Adaptive processes are those that allow living systems to maintain themselves, or survive, in the face of perturbations originating from the environment or the organism itself (Rappaport 1999: 408-410). Adaptations are those behaviours or traits, biologically or culturally inherited, which allow organisms to solve problems related to their survival. A trait is adaptive if it improves the fitness of an organism. We can say a cognitive ability, such as forethought, was adaptive in the context of fire use, if it allowed fire users to solve problems that otherwise would have resulted in not having fire or losing fire at critical times.

The cognitive capacities tabled below are generally considered unique to humans (Amati & Shallice 2006: 357-358). I am concerned with aspects of human executive functions such as response inhibition, delayed consumption and planning, and aspects of social cognition such as self-awareness, theory of mind and collective intentionality. With regard to language I will argue that important preconditions of modern language, such as ostensive signalling, predication and displacement, were implicated in fire use. As such, fire use may be implicated in the evolution of language, human technologies, intentional signalling, metarepresentation, theory of mind, and anticipatory planning.
Table 1 Features of Human Cognition

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I am concerned with humans who could keep a fire going, not those in the process of learning how to do so. While this latter issue is important, it is beyond the scope of the thesis. BothWrangham (2009: 190-194) and Burton (2009: 19-43) have considered how hominins of the Early Pleistocene and Pliocene may have come to be fire users. I will focus on their ideas that relate directly to my argument.

Goudsblom has pointed out (1992a: 4) that using fire was a major social transition, comparable to the later transitions associated with agriculture and industrialization respectively. Throughout human social history we have increasingly domesticated our food and energy resources. Fire use was arguably the first natural resource to be domesticated, and in doing so we came to domesticate ourselves (Goudsblom 1992a: 4). As with farming and industry, there came a time when some human societies became dependent on fire for their survival. I will argue that it was probable some fire users became dependent on fire before fire making had been invented. This issue will be taken up in sections 5.2 and 5.3 below. Therefore, my focus is on the earliest obligate fire users who could not make fire at will and the kind of problems these people had to overcome.
1.6 Review and Organization of the Thesis

The argument of the thesis can be summarized as follows. Societies of competent fire users have existed since the beginning of the Middle Pleistocene. This premise is based on evidence for domestic fires, human brain evolution and migrations into cooler temperate environments. Fire use involved behaving in ways that were costly and cognitively demanding, given the constraints early human fire users had to overcome. These empirical claims ground the argument, except the claim that fire use was cognitively demanding. This claim warrants us to make inferences about the cognitive abilities of fire users.

The main argument of the thesis is that fire related tasks meet the behavioural criteria that reliably indicate some distinctively human cognitive abilities. For example, fire use involved acting in the present to secure a future reward without any proximate intrinsic or extrinsic motive to do so. This meets the behavioural criteria for thinking about the future, thus we can infer forethought from fire use if this were the case. Forethought requires episodic memory. Therefore, it follows that we can infer the capacity to represent episodic memories from fire related tasks that involve acting in the present to secure a future reward.

Arguments from behavioural criteria are supported by evidence and theory that suggest the cognitive abilities of other animals and those that sufficed to forage or make stone tools, may not have sufficed to control fire. So the case that we can infer human cognition from fire use is based on behavioural and comparative inferences. I will also raise possible objections to key premises, and where possible reject them.

Chapter Two will review the literature relevant to the thesis. I review how scholars have tried to explain human cognitive evolution, and how the concept of ‘modern human behaviour’ has not been productive in this respect. I will focus on an alternative approach that is potentially more revealing and assumes that human cognition did not evolve suddenly. The literature relating fire use to cognition is sparse; however some scholars have investigated
aspects of controlled fire that are relevant to our cognitive evolution. These scholars make claims and arguments that serve as a basis for my thesis and my review will focus on their work.

Chapter Three will critically review the direct and indirect evidence for controlled fire use by early humans. The main conclusion to be drawn from the evidence is that some humans have been using fire from the beginning of the Middle Pleistocene around 790 kya. This is a key premise of the thesis because it is important to establish that early humans were using fire, and doing so at a time that has implications for our cognitive evolution. A case can be made that humans were using fire from about 2 mya. However, I am focusing on the later period as it allows me to ground claims about fire use in more secure empirical evidence. I will then discuss which human species might have been obligate fire users and the kind of fires they kept.

Chapter Four describes the ecological conditions Middle Pleistocene humans lived in. I will review the evidence for the paleoenvironments, demographics and lifestyles of early humans. The main conclusions to be drawn are that early humans kept fires in a variety of environmental conditions, living as mobile foragers in relatively small populations made up of relatively small social groups. The aim is to identify the kind of ecological constraint and difficulties early fire using humans would have encountered. Finally, I will discuss the time budgets and possible social organisation of early human fire users in light of the available evidence.

Chapter Five will describe the behaviours fire users engaged in, such as accessing, maintaining and using fire. The key premise that obligate fire users once existed who could not make fire will be discussed in this chapter. I will also describe the social, technological, ecological, economic and demographic constraints early fire users had to overcome. The aim here is to establish why these behaviours were important and the kind of problems early humans overcame to engage in them successfully.
Chapter Six identifies how early humans who could not make fire managed to access and sustain fire. There are many ways to keep a fire and to solve the problems fire keepers would have encountered. We do not know exactly how early human fire users went about this. However, I will argue their options were limited given the universal properties of fire, and what we know about the constraints on early human fire. I will compare different options in terms of their effectiveness and efficiency across a range of contexts fire users would have encountered. From this I will establish the least cognitively demanding behaviours that would have sufficed.

Chapter Seven describes the cognitive abilities I will argue we can infer from controlled fire use. The aim of the chapter is to define the human cognitive abilities at issue and establish behavioural criteria that imply these abilities. I begin with a general definition of cognition and describe how human cognition is different from that of other animals. I then review the criteria used to identify and measure cognition in humans and animals. From this I will establish behavioural criteria that are applicable to the fire related tasks discussed in Chapter Six by describing the cognitive implications of fire related tasks.

Chapters Eight and Nine present the main argument of the thesis focusing on executive functions and social cognition respectively. The argument is that fire related tasks meet the behavioural criteria established in Chapter Seven. This is supported by comparative evidence suggesting great ape cognition may not suffice to engage in fire related tasks. I also argue that humans with these cognitive abilities would have been at an advantage over those without them, because these abilities allowed for more effective and efficient ways to solve fire related problems.

Chapter Eight will focus on executive functions such as working memory, episodic memory and detached representations. Chapter Nine will focus on aspects of social cognition such as informational theory of mind, collective intentionality and intersubjective communication. My focus here is the cognitive processes that enable human modes of cooperation. In this
chapter I will reiterate that the executive functions discussed in Chapter Eight are integral aspects of human social cognition. In both Chapters Eight and Nine I will address possible objections to the arguments presented.

In the conclusion, I will summarise the argument of the thesis in terms of grounds, warrants and pertinence, and how I have met the stated aims of the thesis. I then reiterate the main conclusions of the thesis and their implications for our current understanding of early human cognition. I then outline possible ways to test some premises of the thesis. I will highlight the novelty of my research into the relationship between fire and cognition, and how the thesis compliments and extends on other research in this direction. Finally, I outline research questions that follow from my investigation and how these can be implemented.

1.7 Summary

In summary, my thesis is that we can infer aspects of human cognition from competent fire use, which we can infer from archaeological and fossil evidence. The main premise of my argument is that fire use involved solving cognitively demanding problems, which can be inferred from the complex of fire related tasks fire users engaged in. My conclusions will improve our understanding of how and when fundamental aspects of human cognition, such as executive functions and social cognition, evolved. While fire users did not need modern human cognition to control fire, I will argue they needed a suite of distinctively human abilities that were prerequisites for the evolution of human cognition as it is today.
Chapter Two: Literature Review

2.1 Introduction

I will begin by outlining how paleoanthropologists have tried to explain the evolution of human cognition. I then turn to the literature on the social and behavioural implications of prehistoric fire use. A handful of scholars have addressed various aspects of fire use in relation to the evolution of human physiology (Wrangham 2009), sociality (Wrangham et al 1999, Goullet 2006), civility (Goudsblom 1992a & b), mobility (Rolland 2004), communication (Goudsblom 1989, Ronen 1998), neurology (Burton 2009) and economics (Ofek 2001). My review focuses on the ideas and premises of these scholars that are relevant to the thesis, which I will expand on in terms of their cognitive implications. The relevant literature on cognition, and the behavioural criteria scientists use to identify cognition in humans and animals, will be reviewed in Chapter Seven. I will review the archaeological evidence for prehistoric anthropogenic fires in Chapter Three.

2.2 Early Human Cognition

Scholars are deeply divided as to what early human cognition might have been like. Debates focusing on archaeological signatures for ‘modern human behaviour’ have not been productive (Shea 2011, Proctor 2003: 213-216, Henshilwood & Marean 2003: 627-634, Clarke 2002: 50-52, Wadley 2001: 205-210). Rather than adopt the archaic / modern dichotomy that informs these debates, I will follow those scholars who have proposed that intermediate cognitive types must have existed between our last common ancestor with the apes and humans today (Barnard et al. 2007: 1170-1171, Donald 2001: 260, Mithen 1996 (2003): 162-173).

My assumption is that human cognition did not evolve suddenly in a cognitive or cultural revolution from an apelike precursor. There is good reason to think cognitive abilities and brains have co-evolved (Barnard 2010: 45, Barnard et al. 2007: 1168-1172, Coward & Gamble 2009: 51, 55, Deacon 1997 passim). Rather than focus on signatures or proxies for modern thinking, I will focus on the problems fire using humans faced, and how cognition may have been implicated in solving these problems.

Modern human behaviour or behavioural modernity presumably indicates the presence of humans that were “essentially neurologically and cognitively identical to modern humans” (McBrearty & Stringer 2007: 793). This statement is unclear as it implies that all modern humans are cognitively identical, which they are not. I think what they might mean is that all humans share cognitive affinities not evident in other animals, such as language, and that we have a shared potential for enculturation into any society. One problem with this idea is that humans once existed with the potential for modern human cognition, but without the cultural context required to foster modern cognitive abilities because potential precedes performance.

Archaeologists use the behavioural signatures tabled below to identify the presence of modern human cognition (McBrearty & Brooks 2000: 491-492). It is not certain that all of these behaviours would require human cognition in its current state, although they may require something other than animal cognition. Most of these have been criticised in one way or another as markers of modern human cognition, as has the trait list approach in general (Langley et al 2008, Habgood & Franklin 2008, Brumm & Moore 2005, Speth 2004, Henshilwood & Marean 2003, Wadley 2001).
Complexity of hearth construction is interesting in relation to my argument. Proponents of a Late Pleistocene cognitive revolution are aware that the Neanderthals and probably earlier Middle Pleistocene humans were competent fire users. However, fire use is qualified by the introduction of ‘hearth complexity’ as a criterion for modernity. Despite the general view that fire use has implications for the evolution of human cognition (Darwin 1871: 855, James 1989: 1, Clark & Harris 1985: 3, Ofek 2001: 3, Gowlett 2006: 299, Karkanas et al. 2007: 197, Burton 2009: 29-30, Wrangham 2009: 105-106, Wrangham & Carmody 2010: 197), proponents of a late cognitive revolution seem to presume that controlled fire use does not require any complex human cognitive skills. The implicit reasoning seems to be that Middle Pleistocene humans do not have distinctive cognitive abilities, and these humans can control fire, therefore you do not need special cognitive abilities to use fire.
Leakey describes (1984: 93-94) the standard thinking behind the idea of behavioural modernity, and how the concept has been articulated.

Unlike previous eras, when stasis dominated, innovation is now the essence of culture, with change being measured in millennia rather than hundreds of millennia. Known as the Upper Paleolithic Revolution, this collective archaeological signal is unmistakable evidence of the modern human mind at work.

This idea has been the dominant paradigm in paleoanthropological research for the last three decades. However, more continual or inclusive models that recognize, and try to evaluate, the place of earlier humans in the evolution of cognition are becoming increasingly influential (Donald 2001: 260, Barnard et al. 2007: 1170-1172).

Despite theoretical and empirical problems with the concept of modern human behavior, the view that a cognitive transformation occurring sometime between 120-60 kya gave rise to the modern human mind is persistent. However, by focusing on modern human behaviour as a proxy for modern human cognition, paleoanthropologists have set themselves up to see sharp oppositional differences instead of variation along a continuum (Marean & Thompson 2003: 166).

A key difficulty with this idea is that we are increasingly finding signatures of modernity in association with humans, who supposedly lack modern cognition, from earlier periods than predicted by the cognitive revolution model (Langley et al. 2008). Also, some people who we know to be cognitively modern do not always exhibit the archaeological signature for cognitive modernity (Holdaway & Cosgrove 1997). Evidence from stone tools suggests the long-standing assumption that vast behavioural differences exist between Middle Pleistocene and later humans is almost certainly wrong (Shea 2011: 14). This means the reliability of modern human behaviour as an indicator of cognition is compromised. As Shea points out we need to consider the concept of ‘behavioural modernity’ more carefully, the trait list approach could be fundamentally flawed, and we should focus on strategic
variation of particular behaviours rather than bundling them together into higher-level constructs (2006: 43).

Another problem using modern human behavior as a proxy for modern cognition is that it identifies modern cognition after the fact. For example, problems with some of the behavioral criteria for modern cognition have led to a focus on archaeologically evident forms of symbolism. “From the archaeologists viewpoint it is only when symbolism is stored outside the human brain that there is irrefutable evidence for cultural modernity” (Wadley 2001: 215). The difficulty with this condition is that the symbolic behaviour at issue indicates people who we think already have modern cognitive abilities or modern minds. As such, external symbolism, important as it is, cannot identify the precursors to modern cognition that must have preceded the emergence of external forms of symbolic representation. To understand how and why modern human cognition evolved we need to know how, why, and when the precursors of human cognition evolved. Therefore, we must look to earlier behavioural adaptations and contexts that might have selected for human cognitive skills in the first place, and that facilitated the transition to modern human cognition.

Some scholars recognise that early humans went through some form of proto-language phase, involving a form of symbolic reference, but lacking the complex syntax of modern languages (Bickerton 2009: 40-41, 2003: 77-93). The sheer complexity of language and the neural mechanisms that enable language tell us that language did not evolve suddenly (Deacon 1997 passim, Pinker 1995 passim). Proto-language could have involved vocalisations (Bickerton 2009 passim), gestures (Corbalis 2003 passim), or mimetic performance (Donald 2001: 260) as a medium. It is reasonable to think a communication system involving symbolism preceded complex syntax. Without a corpus of symbolic signs, and communicators who understand how to use them meaningfully to exchange information, language as it is today would not have evolved. However, such a language is not necessarily going to leave any external archaeologically visible forms of symbolism.
I am assuming that human cognition did not evolve directly from an ape-like precursor. Brain and cultural evolution during Middle Pleistocene tells us something was going on in the intellects of early humans. Largely viewed as a period of cognitive stasis, the Early and Middle Pleistocene is now being considered more seriously as an evolutionary bridge leading from apelike to humanlike cognition (Barnard et al. 2007 *passim*). It is unlikely when considered from this perspective that the cognition of Middle Pleistocene humans, as inferred from their way of life, was closer to that of modern apes than modern humans as has been suggested (Lewis-Williams 2002: 92-92, 285, Jordan 1999: 96, Diamond 1992: 27). Diamond has proposed that Middle Pleistocene humans were “little more than glorified chimpanzees” in the ways they made a living (1992: 27). I will argue that fire use suggests this is an inaccurate assessment, notwithstanding the tool making and foraging behaviours of early humans.

Perhaps the most developed and comprehensive model linking the cognition of primates to modern humans is the series of increasingly complex evolving cognitive architectures proposed by Barnard et al. (2007). Excluding ‘the cultural revolution model’, the most influential model of cognitive development has arguably been Donald’s four-stage model (Donald 2001: 260), with an entire publication dedicated to his ideas (Scarre & Renfrew 1999). Both these approaches effectively diffuse many of the inherent problems of the cognitive revolution model, and provide us with another way to think about the evolution of cognition in relation to archaeological evidence. Combined with a developmental systems theory approach, as described in section 1.5 above, we now have more refined ways to think about the evolution of cognition in relation to the available lines of evidence.

In summary, the trait list approach focusing on archaeological signatures of modern human behaviour has not contributed greatly to our understanding of how human cognition might have evolved. The debate over Neanderthal and modern human cognitive differences has tended to cloud our understanding of early human cognition. Received ideas have inflicted lasting damage on scientific thought and literature. The notion of Neanderthal
cognitive ineptitude is deep and pervasive because it reassures us about ourselves (Otto 2000: 271). Scholars are beginning to focus on behaviours that may indicate intermediate cognitive abilities that would have been important precursors to modern human cognition. My thesis, as far as I know, is the first detailed attempt to relate fire use to evolving human cognition, and establish whether or not fire use can serve as a basis for making inferences about early human cognition.

2.3 Fire Use and Communication

Goudsblom (1989) and Ronen (1998) have suggested that fire use was implicated in the evolution of language. To my knowledge, no other scholars have directly addressed this issue. Davidson has mentioned fire use as providing possible insights into language origins, but dismisses the evidence for Middle Pleistocene controlled fire use (2003: 152). Goudsblom has suggested fire use was a major social transition in human history comparable to the advent of farming and then industrialization (1992a & b). I will review the thoughts of Goudsblom and Ronen on the possible relationship between the domestication of fire and the evolution of language.

Goudsblom (1989: 159) and Ronen (1998: 445) note that while tool use, language and fire use are universal human behaviours; only fire use is exclusively human, as some animals use rudimentary tools and can communicate in language-like ways. Goudsblom stresses that he is not suggesting a monocausal relationship between fire and the emergence of language (1989: 159). Fire use, unlike many complex animal behaviours, is culturally learned, transmitted and shared, not biologically predetermined or learned through observation alone (Goudsblom 1989: 159).

Goudsblom makes several points that I will develop in the thesis. Gathering fuel and tending a fire involved ‘deferred gratification’ as these behaviours are not always performed in an individual’s immediate interest, but directed at future rewards (Goudsblom 1989: 165). Fire use involved cultural transmission to ensure fire related skills were not lost and that fire related responsibilities and duties were understood (Goudsblom 1989: 166). It
involved social coordination to ensure fuel was gathered, the fire was tended and that it was not misused (Goudsblom 1989: 166). Fire users, while using fire for their own ends, also had to “submit to its social and psychological demands” (Goudsblom 1989: 166). As such, fire use required what Goudsblom refers to as a kind of ‘self-domestication’ or ‘civilization’ (Goudsblom 1989: 166). Today we recognize the cognitive underpinnings of the kind of self-control or self-regulation Goudsblom is alluding to as executive control or executive functions. These were not only required for fire use, but reinforced by it (Goudsblom 1989: 165)

Goudsblom also presents an evolutionary argument. Groups that managed to maintain control over fire had an enormous advantage over those that could not (Goudsblom 1989: 169). This put a “high premium” on social coordination and planning, which “must have been greatly enhanced by symbolic communication” (Goudsblom 1989: 169). The domestication of fire was important for the evolution of language because fire use provided a context in which language would have been highly adaptive. He points out that fire would have served as a focal point for social interaction and for establishing joint attention (Goudsblom 1989: 169). For these reasons Goudsblom suggests that fire use would have been conducive to the evolution of language (1989: 169). The idea that using fire established an advantageous context in which aspects of executive control, social cognition and linguistic communication would have been adaptive will be developed throughout the thesis.

In an effort to avoid the problems associated with using behavioural modernity as a proxy for human cognitive origins, Ronen tries to identify the earliest archaeologically evident behaviour that could not have been performed without language (1998: 439). He identifies fire use, in contrast to foraging or tool making, as such behaviour. Ronen suggests that fire provisioning is different from food and tool provisioning systems, which evolved earlier.
Firstly, he points out that fire use is uniquely human in ways that foraging and tool use are not, which may “hint” at the operation of human social and cognitive skills (Ronen 1998: 443). Ronen’s other observation is that the fuel supply does not immediately affect the fire. Unlike food provisioning and tool provisioning systems, fire provisioning is not an integrated system (Ronen 1998: 443). Tending the fire does not follow immediately from gathering fuel. Individuals cannot associate need and trigger as clearly as they do with food and tools. Thus, the fire provisioning system is a “detached system, involving planning to a greater extent” than these other systems (Ronen 1998: 443).

Fire use was a social activity (Ronen 1998: 443). Ronen points out that keeping a fire involved the entire group cooperating over extended periods, and that “the burden of supplying fuel brought only delayed benefits” (1998: 444). This kind of cooperation involving collaboration directed at securing future outcomes appears to be distinctively human (Ronen 1998: 444, Gärdenfors 2008 *passim*). The argument that fire use would have required social interactions that demanded human social cognition will be developed throughout the thesis. In particular, I will focus on the implied theory of mind, collective intentionality and intersubjective communicative skills fire use might have involved.

Ronen connects language to these aspects of fire use by pointing out that human language allows discussion of previous experience or future plans and instruction, whereas primate communication does not (Ronen 1998: 443). In summary, he argues that keeping fire involved representing and transmitting displaced and predicate information related to the practical and social aspects of fire use. This required symbolic reference, which is a distinctive feature of human language (Ronen 1998: 445).

Ronen also makes some general observations (Ronen 1998: 445) relating fire use to language and human cognition. Fire use involves realizing the potential benefits of an apparently dangerous substance; conceiving of something as other than what it apparently is. It would have involved notions
of permanence and disappearance, and success and failure. Success depended on testing cause and effect relationships, learning from past experience, and planning accordingly. Fire users needed to communicate prohibitions, in particular to children. They had to measure quantities such as fuel loads and supplies, which implies mathematical abstraction. All these features, he suggests, “mean a human communication system” (Ronen 1998: 445). Ronen does not explore these claims in any detail. While his ideas seem plausible we need to make more explicit connections between fire use and these suggested requirements, and these requirements and human cognition. A key focus of the thesis is to further develop some of Ronen’s claims.

Both Ronen and Goudsblom point out how fuel gathering is ‘detached’ from the tangible benefits a fire provides. This alone may distinguish controlled fire use from other behaviours early humans were engaging in. The claims outlined above are in stark contrast to the claim that fire use like food gathering and tool making was a mundane behaviour that rarely, if ever, required executive functions (Coolidge & Wynn 2007: 81). According to Coolidge & Wynn (2007: 81) using fire can be accomplished with routine plans of action and procedural memory. It should be noted that Coolidge and Wynn do not present a case for why fire use does not require more complex cognitive operations in much the same way that Goudsblom and Ronen do not present a detailed case for why it does.

### 2.4 Fire Use and the Social Intelligence Hypothesis

The social intelligence hypothesis posits that the complex social worlds in which primates live provided the selective pressure that has driven primate and human brain evolution. The complexity of ape, including human, intelligence is an adaptive response to the social environments in which primates interact (Sterelny 2007: 720). Gowlett suggests a possible relationship between the social intelligence hypothesis, also known as the social brain hypothesis, and fire use (2006: 306-307).

Early versions of the hypothesis emphasized competitive manoeuvring as agents anticipate and counter-anticipate the responses of others in
competition for scarce resources. Others have focused on socially mediated learning rather than Machiavellian manoeuvring (Sterelny 2007: 720). Dunbar stresses the importance of maintaining social coherence in response to increased group size and restricted time budgets (1996 *passim*).

In what way are primate social worlds more complex than those of other animals? Dunbar and Shultz point out (2007: 1344) that in primates the relative size of the neocortex is positively associated with many indices of social complexity such as, number of females, group size, grooming clique sizes, male mating strategies, the frequency of coalitions, the prevalence of social play, the frequency of tactile deception and social learning. Individuals living in stable social groups face cognitive demands that those living alone do not, in particular with respect to the maintenance of social cohesion (Dunbar & Shultz 2007: 1345). As Dunbar and Shultz suggest (2007: 1345), meeting individual requirements, while coordinating behaviour with others, involves defusing the direct and indirect conflicts generated by foraging in the same area and competing for scarce resources.

Dunbar and Shultz point to a correlation between relative neocortex size and pair bonds in several taxa, and suggest two reasons why social bonds or monogamy may be cognitively demanding (2007: 1346). Firstly, monogamy is a risky lifelong commitment so care must be taken in choosing mates who will be loyal and committed to their role in rearing the young. Secondly, parental investment requires behavioural synchrony and “very close coordination” to regulate parental duties with individual needs so as to ensure duties are time-shared evenly (Dunbar & Shultz 2007: 1346).

Humans have taken primate sociality to a new level. Experimental evidence suggests we, unlike our primate cousins, are ‘strong reciprocators’ (Sterelny 2007: 723, Tomasello et al 2009 *passim*). This means that humans generally enter into cooperative social interactions, even with strangers, expecting others to cooperate and willing to punish the uncooperative. “Human ultrasociality depends on the fact that most humans are default cooperators” (Sterelny 2007: 723). Evidence suggests that humans in general
enter into social interactions expecting others to cooperate, responding to cooperation by cooperating further and with a preparedness to punish non-cooperation at a cost to themselves (Sterelny 2007: 723). However, some individuals will take opportunities to cheat, or refuse to cooperate, to further their own ends. I will argue that fire users had to deal with free riding.

Researchers investigating the evolution, development and cognitive implications of prosocial cooperation in humans focus on reciprocity and collaboration (Tomasello et al. 2009, Van Vugt & Van Lange 2006, Stevens & Hauser 2004, Binck & Gärdenfors 2003). The social requirements of reciprocity are cognitively demanding because they involve effective scrutiny that requires identifying agents and representing both their past and potential actions (Sterelny 2007: 723). Cooperation is more cognitively demanding when it involves monitoring defections, divisions of labour, complementary tasks conducted remotely, delayed benefits or being aware of and adjusting to the behaviour of others (Sterelny 2007: 725). This is because these social oriented behaviours involve representing the covert intentions of others and trusting that they will act appropriately.

Scholars have suggested hunting coalitions, collective defence, enforcement coalitions, collaborative foraging and cooperative breeding as possible early human behaviours that would have generated a joint benefit that would have improved the inclusive fitness of cooperators (Sterelny 2007: 724). They stress the need for enforcement coalitions to maintain the social order against would be defectors or alpha males that undermine cooperative activities (Sterelny 2007: 724). Strong reciprocation and social norms directly support prosocial action in human societies in the following ways (Sterelny 2007: 723-724),

norms can…stabilize behaviour by making the informational environment of strong reciprocation transparent…make explicit the requirements of reciprocity…reduce the cost of calculation…and by making the expectations of others unambiguous and explicit…make failures to cooperate both salient and negatively marked.
I will argue that fire use established a focus of collective action that would have selected for enhanced social cognition. The behaviour of other apes does not imply the kind of collective action associated with fire use. Nor are other Middle Pleistocene behaviours, such as tool making or hunting, similarly complex in terms of the required group level coordination focused on a future reward. Fire use very likely would have enhanced the adaptive value of collaborative behaviours. I will argue that fire use can help us understand how and why human social cognition evolved, because fire use involved delayed reciprocity, establishing and enforcing social norms, coalitions capable of excluding bullies, and effective means of detecting and deterring free riders.

Gowlett has suggested (2006) a possible link between using fire and the social intelligence hypothesis. The pattern of Middle Pleistocene fire use implies a division of labour to sustain fires, and to bring in fuel (Gowlett 2006: 307). Middle Pleistocene fires required investments that suggest the need for a strong local social network (Gowlett 2006: 307). This is because if Middle Pleistocene humans could not make fire at will they probably had to regain fire through network links (Gowlett 2006: 307). That early humans relied on other humans, or at least their fires, to regain fire will be a key premise of the thesis. Gowlett suggests (2006: 307) that within group social coordination would have been necessary for replenishing the fire and for managing fire maintenance alongside other subsistence activities. In extreme conditions social networking would be at a premium, as this is when fire would have played a crucial role in survival (Gowlett 2006: 307, Gilligan 2007: 501). Enhanced social intelligence would have been advantageous in coordinating these activities and monitoring the behaviours of other group members.

2.5 The Expensive Tissue and Cooking Hypotheses

Both these hypotheses help to identify when early humans may have began using fire and how they may have used it. Evolution is an economical process that does not produce needless organs, capacities or behaviours that are costly to maintain (Dunbar & Shultz 2007: 1344). It follows that costly
adaptations were selected for because of the reproductive advantage they conveyed (Dunbar & Shultz 2007: 1344). Some features can evolve through mechanisms other than natural selection, such as drift or as exaptations. However, all things being equal, smaller brains will be selected for, given the high metabolic cost of neural tissue, the increased pre-natal and post-natal cost of development, and the increased risks involved with childbirth (Schoenemann 2006: 391). When relatively large brains do evolve we can be reasonably sure they provide their possessors with some adaptive advantage because “strong selection is required to account for the expansion and consequent costs involved” (Coward & Gamble 2009: 54).

Our highly encephalized brains are metabolically expensive to grow and maintain. Human brains are three times larger than expected for a primate of our size, and six times larger than expected for a mammal (Byrne 2000: 543). This prompted Aiello and Wheeler to ask how primates, including humans, can afford large brains (1995: 200). One possible solution may have been to reduce the energy demands of another costly organ, so that energy can be redirected to the brain (Aiello and Wheeler 1995: 207). Aiello and Wheeler identify the heart, kidney, liver and gastro-intestinal tract (gut) as other expensive organs (Aiello and Wheeler 1995: 204). They note that compared to other apes humans have a very small gut as well as a very large brain. They also note that the other expensive organs such as the heart, liver and kidney are less amenable to reduction, given the important functions they perform and consequent risk involved (Aiello and Wheeler 1995: 205-206).

Thus, it could be that our smaller gut allowed for our larger brain. However, for a smaller gut to evolve a substantial improvement in diet, relative to that of other apes, was required. There is evidence to suggest hominins adapted to an improved diet during human evolution (Ungar et al. 2006: 222), which was more cognitively demanding to procure (Aiello and Wheeler 1995: 207). This may have removed the energy constraint on brain evolution by reducing the gut, and more complex foraging behaviour provides selective pressure for the increased intelligence large brains provide (Aiello and Wheeler 1995: 207). To understand how and why human brains evolved
we need to understand two things: what relaxed the constraints on brain evolution and what adaptive problems did having a big brain solve (Dunbar and Shultz 2007: 1344)? In the controlled use of fire we have a potential answer to both these questions. Cooking implies improved diet quality, and, as I will argue, fire use increases cognitive demands in a variety of ways.

The expensive tissue hypothesis may help to explain how early Homo came to be more encephalized than the australopiths, and our last common ancestor with chimpanzees. The general consensus is that early Homo was eating more meat and vegetal type foods than the australopiths, although there is little support from the fossil and archaeological evidence that early humans were targeting specific foods (Ungar et al. 2006: 222). Specialisation of underground storage organs (root vegetables) without cooking is also unlikely for nutritional reasons (Ungar et al. 2006: 221, Stahl 1984: 156). There is evidence that Homo erectus ate more meat than earlier humans (Ungar et al. 2006: 221). Although early human diets are difficult to assess, Ungar et al. propose (2006: 222) that the fossil evidence, combined with archaeological remains and paleoenvironmental indicators suggest Homo erectus had adapted to a more flexible, versatile subsistence strategy than earlier humans. However, it is not certain that a diet of more meat and more root vegetables would have been all that more nutritious without cooking (Wrangham 2009: 37-53, Stahl 1984 passim). Large quantities of raw meat was probably difficult for humans like Homo erectus to process and digest as it is for modern humans (Wrangham 2009), and many plant foods are toxic without cooking (Stahl 1984: 156).

Encephalisation quotients measure the proportionate relationship between body mass and amount of neural tissue. Trying to access body mass and gut size with limited postcranal remains is difficult (Ruff et al. 1997: 173). However, we do have some postcranial remains for assessing Homo rudolfensis and Homo habilis, and good evidence to suggest Homo erectus

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5 Brain size is correlated with body size in that larger animals have larger brains. It is therefore important to consider relative brain size when considering metabolic costs and cognitive potential.
had essentially a modern human body, and by inference a relatively similar gut size. The problem for the expensive tissue hypothesis is that human brains continue to increase in size during the Middle Pleistocene with no further correlated evidence for further reductions in gut size or for a substantial increase in body mass.

The encephalization quotient for *Homo rudolfensis*, *Homo habilis*, and early *Homo erectus* would have been roughly equal at around 3.4 to 3.8 (Ruff et al. 1997: 173), if our body size estimates are accurate. This increases to within the range of modern humans between about 750-200 kya. This ‘brain boom’ is far more impressive than the earlier trend because it is not correlated with any significant increase in body mass (Calvin 2004: 45-50). While there is no evidence to suggest gut reductions can account for this later increase, nutrition may still be a key. One way to extract more nutrition from food and improve diet breadth without changing the gut is to cook what you eat (Wrangham 2009 *passim*).

Wrangham and colleagues argue that a small gut, a small mouth and a large brain indicates the regular consumption of cooked food by humans (Wrangham 2009 *passim*, Wrangham & Carmody 2010: 169). We seem to be biologically adapted to eating cooked food. This suggests, cooking, and by inference fire use has played an important role in human biological evolution, for perhaps millions of years. The cooking hypothesis is discussed further in section 3.3 below. Increases in relative brain size and transitions to modern human bodies may be potential markers of controlled fire use.

This means that we may be able to identify the origin of obligate fire use from human biology without reference to the evidence for domestic fires.\(^6\) Wrangham suggests (2009: 96) three periods in which cooking may have emerged: around 2.5 to 1.8 mya, around 800 to 500 kya, or 200 kya, favouring the emergence of *Homo erectus* 2.5 to 1.8 mya, as the time cooking

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\(^6\) While archaeologists might not accept this (Roebroeks & Villa 2011), Wrangham’s argument is sound and the evidence compelling. The question is not did *Homo erectus* leave evidence for fire use, but could *Homo erectus* have survived on a diet of raw food?
became a regular human behaviour. However, I will focus on the transition between 800 and 500 kya because the case for cooking as a means to meet energy demands is stronger and we have clear evidence for fire use from around the beginning of the Middle Pleistocene. This assumes early *Homo erectus* were not obligate fire users, whereas some *Homo erectus* populations from about 1 mya probably were.

The role of nutrition in brain evolution is important to my argument. Cooking, and by implication fire use, are related to better nutrition and Wrangham has argued (2009) that cooking played an important role in the evolution of human features such as relatively small mouths, small guts and large brains. From this we can infer that regular cooking, and by inference regular fire use, evolved prior to 750 kya or even as early as 2 mya.

2.6 Fire Use and Central Placed Foraging

This section reviews Rolland’s argument (2006) for the emergence of controlled fire use and the implications of this for human land use and mobility. He makes two proposals that are relevant to my thesis. The first is that the emergence of fire use was a punctuated event occurring around 400-350 kya (2004: 248). The second is that fire use led to the establishment of home bases (2004: 270-271). The first claim is arguably wrong, at least in terms of timing. The second is probably correct, and important for understanding changes in human mobility, land use patterns, social organisation and foraging strategies, all of which have cognitive implications.

Rolland makes the point that fire use, like language, is emergent because it is without precedents in the animal world (2004: 250). However, fire use is less complex than language, not being dependent on the raft of evolved neurological, physiological and cultural features that have co-evolved with language (Rolland 2004: 250). As such, fire use could have emerged suddenly, where as language could not. There is no reason to think active fire use could not have emerged suddenly and spread quickly if groups that could access and maintain fire were at an advantage over those that could not.
The empirical support for his first claim is that the earliest unambiguous evidence for domestic fires clusters around 400-350 kya. (Rolland 2004: 259). When Rolland’s paper was published this was a reasonable assessment of the available evidence. However, we now have reasons to think fire use emerged earlier than this. The absence of evidence for domestic fires may be a consequence of taphonomic processes rather than an absence of fire use (Sergant et al. 2006: 999, Preece et al. 2007: 1282). The lack of evidence for earlier domestic fires may be due to the fact that such evidence is not likely to survive. Few sites exhibit the kind of preservation potential required for evidence of fire to survive. As Gowlett suggests (2006: 307), we have positive evidence of erosional factors that would have obliterated most early evidence for domestic fires in Northern Europe and Asia prior to 400 kya.

We now have direct evidence that some humans were using fire from the beginning of the Middle Pleistocene 800-700 kya at Gesher Benot Ya’aqov in Israel (Alperson-Afil & Goren-Inbar 2010). A key premise for the claim that fire use emerges around the 400-350 kya mark, is that there is no clear evidence for anthropogenic fires prior to this time. We now have good evidence to suggest that this is not the case. It is also probable that the Zhokoudian Locality 1 site in China, which Rolland suggests provides evidence of early human fire use (2004: 266-269), is dated to around 780-680 kya, not 500-400 kya as previously thought (Shen et al. 2009).

The indirect evidence for brain evolution also argues against this late date for the emergence of fire use. By 400-350 kya human brains are beginning to fall within the modern human range (Schoenemann 2006: C-3), although Homo heidelbergensis and early Neanderthals may not have been as encephalized as Homo sapiens (Ruff et al. 1997: 174). The rapid brain increase that occurs between about 750 and 250 kya (Calvin 2004: 44-50), or 600 and 150 kya (Ruff et al. 1997: 174, Rosenberg et al 2006: 3555), depending on how one interprets the evidence, is unprecedented. It is unlikely that this brain increase could have occurred without the extra nutrition and energy cooked foods provide (Wrangham 2009: 114-127, Carmody &
Wrangham 2009 *passim*). If this were the case then regular cooking, and by inference fire use, must have been in place sometime before this increase begins around 750 kya. Therefore, it is reasonable to think populations of fire using individuals have existed from the beginning of the Middle Pleistocene.

Rolland argues (2004: 259-262) that fire use implies central placed foraging, which was a major shift from earlier hominin land use patterns. He distinguishes between the ‘core areas’ of earlier hominids and the ‘home bases’ of fire users proposing that fire use was instrumental in establishing the latter. In core areas processing meat had to be conducted at different locations from socializing and sleeping (Rolland 2004: 259-262).

Hominins in these circumstances needed safe daytime places that were secure from the threat of predation, particularly towards the young, and somewhere to sleep. Places where meat was being procured, processed and consumed are not safe as they attract predators. Early hominids would have moved around core areas to accommodate these needs (Rolland 2004: 259-262). The archaeological evidence from the Early Pleistocene is scarce by contrast to later periods, and at much lower resolutions, but may indicate a core area pattern (Rolland 2004: 259-262). In contrast, home bases, courtesy of fire use, are places where vulnerable individuals are safe, meat and other foodstuffs can be introduced and consumed, tools can be made and maintained, grooming can take place and you can sleep (Rolland 2004: 263).

The emergence of home bases could be directly correlated with the emergence of controlled fire use. Importantly for the evolution of cognition, home bases changed the way hominids represented and moved about the landscape, procured food and other resources, made decisions about what to do, and the way they interacted socially. They are places where vegetal and

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7 Sleeping on the ground might always have been a risky option for early humans without fire (Hart & Sussman 2009, Coolidge & Wynn 2006).
8 Rolland seems to implicitly assume, as do most scholars, that fire provides protection from predation. While this is a reasonable assumption, we need to be more explicit about how fire does this. To me it is not a given that large predators would be afraid of a domestic cooking fire.
animal foods are introduced, shared and consumed. They provide a setting favouring the transmission of knowledge, through prolonged learning of shared and transmitted technical and socio-economic cultural traditions. Individuals, in particular the young, can more easily learn the cognitive repertoires necessary for ensuring group survival (Rolland 2004: 263). Learning to control fire effectively and efficiently would have been important in this respect.

2.7 The Economics of Fire Use

Ofek (2001) investigates the economic and evolutionary consequences of using fire in relation to logistical constraints facing early humans. He proposes that “fire use facilitated, and was facilitated by, early forms of market exchange” (2001: 153). In support of this claim Ofek establishes several premises that are important to my argument. I will briefly summarise his argument then outline the premises of critical importance to my own. One aim of the thesis is to develop some of Ofek’s pertinent observations by investigating their cognitive implications.

Ofek points out (2001: 158) that keeping a fire going continually was difficult from a logistical perspective; perhaps more difficult than for people with access to ignition technologies. He suggests that this is the most interesting period in the prehistory of fire from an evolutionary and economic perspective. “This period entailed special arrangements in division of labour at different levels of social organization…I am not sure that our account of prehistoric events always pays due credit to this particular aspect of human history” (Ofek 2001: 158).

Ofek suggests (2001: 159-160) early human fire uses probably did not maintain communal fires because of free riding, and because we cannot expect that a few individuals maintained a fire for everyone in the group. He suggests (2001: 159-160) communal fires were probably not an alternative in the early stages of fire use. My own argument will focus on the communal fire scenario as the most probable early form of fire use, for reasons discussed in section 4.6 below. Ofek suggests (2001: 160) a more reasonable option is
the ‘private fire’ scenario, whereby individuals, families or sub-groups maintain their own fires separately from their co-residents.

However, the problem with the private fire scenario is freely available fire for those unable, or unwilling, to undertake the task of continual maintenance. In a society where fire can be gained at no cost such individuals would probably be at an advantage over those that incur the cost of fire maintenance. If fire is available for free it is not in anyone's interest to undertake the painstaking task of maintenance (2001: 160). What you end up with is a system of only borrowers and no donors, and no fire. Ofek suggests (2001: 160), this apparently did not happen, and that new forces must have taken over that led to a more stable equilibrium.

Ofek’s solution to the problem of free riding is the ‘incendiary hub’ scenario. He suggests, “A system of centrally propagated but privately consumed (and fuelled) fires is far superior” to either a private or communal fire scenario (Ofek 2001: 161). The advantage of such a system is groups could reduce the cost of fuel gathering and fire maintenance, while still enjoying a reliable ignition source. However, for this system to work you need a small group of well rewarded, well motivated, fire specialists who traded fire for some due reward. Ofek’s solution is that early human fire use required an incipient form of mercantile exchange and as a contrived commodity “fire was in the ideal position to incite the creation of this very mechanism” (2001: 161).

Ofek presents a compelling argument with clear implications for the evolution of cognitive capacities that support commodity exchange. Throughout the thesis his arguments will be expanded on, in particular, the problem of free riding in relation to domestic fire as a public good. Although I will argue that there may have been other options available to early humans than the incendiary hub, I will support the argument that fire users had to, and ultimately did, solve the problems associated with free riding.
I will now outline some of Ofek’s observations about the nature of early human fire use that are important to my argument. A fire that burns continually will consume a lot of energy relative to the usable energy it produces (2001: 153-167). The consequence of this is that humans who used fire to cook, for warmth and for protection had to use up lots of energy keeping the fire going when it was not being used. For example, early humans may have maintained a fire continually that they only cooked on once a day.

A fire that must burn continually needs to be an optimal size. If it is too small it is prone to going out, and if it is too big it is inefficient because the core temperature is very high and fuel is consumed more quickly (Ofek 2001: 153-157). Fires also need to be big enough to cook with, keep you warm or ward off predators. Optimal size fires will quickly use up all the fuel in an increasing radius from the fire. This means the distances fire users had to travel each day increased the longer a group stayed in the one spot. This is a problem because for people who must walk everywhere a kilometre is a measure of energy not distance (Ofek 2001: 153-157). This problem is compounded because early humans lacked efficient logging equipment, and the means to carry heavy loads other than by collaborating (Ofek 2001: 153-157). This means early humans relied on either fast burning dry wood or inefficient greenwood gathered from relatively increasing distances.

The problem is compounded for cave users if other resources were not close by (Ofek 2001: 162-167). A cave dweller who must make a round trip of two kilometres to drink, walks an extra 730 km a year compared to someone camped right next to a river or lake. If we consider the potential for increased travel costs coupled with the increasing daily cost of gathering fuel and foraging, then “a cave was a dwelling the average hunter-gatherer could hardly afford” (Ofek 2001: 266). Yet many early human fire users managed to occupy caves. Fires are prone to going out in rain. Thus, early humans had to invest some time and effort in preventing this from happening. This may be why they opted to live in caves despite the added costs (Ofek 2001: 162-167), but we cannot be sure.
Ofek points out that “A central fire open to all has all the elements of a public good” (2001: 159). All members of the group benefited from having access to fire, but not everyone need pay for its upkeep. Public goods are invariably subject to free riding, with some individuals receiving the benefit, but not contributing to the cost. This can lead to unstable economic situations, whereby excessive free riding results in a failure to maintain the good. Free riders probably had to be detected and sanctioned, discouraged or excluded, for fire use to become a stable behaviour, and this is cognitively demanding.

2.8 Summary

I will now summarize the main points to be drawn from this review. Paleoanthropologists tend to adopt a minimalist view of early human cognition. Middle Pleistocene humans are often presumed to lack foresight, self control and social cognitive skills beyond that of the other great apes. This view is derived from the concept of modern human behaviour. The theory of modern human behaviour predicts that modern human cognition will be associated with a range of archaeologically evident signatures. Evidence for modern human behaviour is assumed to be a reliable indicator for modern human cognition. Although the absence of modern behaviour does not necessarily imply the absence of human cognitive abilities, many paleoanthropologists have interpreted the evidence this way.

The concept of modern human behaviour has not helped us to understand how and when important precursors of human cognition evolved. We are now beginning to investigate behaviours that may indicate intermediate cognitive types bridging the gap between non-human apes and humans today. In contrast to other lines of evidence, such as tool use and subsistence strategies, fire use has high potential to be informative with respect to cognition, albeit the least investigated. By focusing on an evident behaviour, and the practical problems early humans had to solve to engage in that behaviour, I aim to circumvent the inherent biases and limitations of the modern human behaviour approach.
Both Gouldsblom (1989) and Ronen (1998) suggest that fire use involved a range of cognitively demanding behaviours such as delayed consumption, inhibiting responses, representing displaced information, explicit instruction involving cultural transmission and enforcing social norms. They suggest that fire use would have required and facilitated linguistic communication. These are significant cognitive skills in terms of evolving human cognition, even without the implications for language evolution. This is because we do not think these abilities are well developed in the other apes, and we think they would have been important prerequisites for complex human communication, culture and cognition to evolve. My thesis develops the suggestion that fire use involved inhibiting responses, delaying gratification, thinking about the future and transmitting complex cultural information.

Primate social intelligence may have evolved in response to the complex social worlds most primates must negotiate (Dunbar & Shultz 2007). The relatively large brains of primates may be correlated with social complexity. Explaining the evolution of social intelligence in humans requires accounting for the reduced constraints on brain evolution, and identifying behaviours that would have selected for enhanced social cognition. We need to account for our tendency to cooperate with non-kin and the fact that humans in general are strong reciprocators. I will argue fire use established an advantageous behavioural context in which humanlike cooperation and strong reciprocity were adaptive. Fire use can also help us understand how Middle Pleistocene humans, by virtue of cooking, overcame constraints on brain evolution.

Gowlett has related controlled fire use by Middle Pleistocene humans to the social intelligence hypothesis (2006). He suggests fire use would have involved cognitively demanding behaviours such as a division of labour to sustain the fire and bring in fuel, coordination at the group level to maintain fire in conjunction with other behaviours, and social networking with other groups to ensure access to fire. I will develop arguments for why these
behaviours were involved in fire use, and why they are cognitively demanding with respect to social cognition.

The expensive tissue and cooking hypotheses suggest Middle Pleistocene humans could not have survived without fire. Increasing energy demands, from *Homo erectus* to *Homo sapiens*, marks human evolution. This is indicated by several measures of energy costs. During the Early and Middle Pleistocene human body size, foraging range, relative brain size, duration of gestation and duration of postnatal dependence increases (Aiello & Wells 2002). This occurs during a period when the human capacity to digest food seems to be decreasing. This could be the result of an improved diet relative to that of the other apes. A raw food diet is less nutritious than one regularly supplemented with cooked foods.

The transition from early homo to *Homo erectus* could possibly have occurred without the added energy cooked food provides, and the extended range of foods cooking allows, although Wrangham does not think so (2009: 96). It is unlikely that humans with even greater energy demands than *Homo erectus* could have evolved without regularly eating cooked food. Modern human foragers would struggle to survive without cooking. Therefore, we have no reason to think humans with similar energy demands could have. The consequence of this is that most Middle Pleistocene humans were obligate cooks, and by inference obligate fire users. This may include late *Homo erectus*, and later human species with larger brains. This implies Middle Pleistocene humans had to learn effective cooking methods and the social obligations that allowed individuals to cook.

Rolland has argued (2004) that controlled fire use emerged suddenly around 400-350 kya. We now have reason to think this is incorrect. Fire use led to the establishment of home bases in human populations – safe locations where a range of different activates can be conducted such as food processing and consumption, tool making, socialising, rearing young and sleeping. Home bases imply a shift to central placed foraging, which changed the way humans moved about and represented the landscape, and organized subsistence
strategies. The shift to central placed foraging has cognitive implications for cooperation, spatial memory and social organization.

Ofek discusses the logistics and practical constraints of controlled fire use from an economic perspective (2001). He points out that fire users must contend with practical problems such as increased transport distances, low quality fuel and accessing fire. Fire use will lead to excessive free riding if individuals who do not incur the cost of keeping fire can access it at no cost from others who do. Mechanisms had to evolve to deal with the problem of free riding. Ofek suggests a system of specialist fire keepers providing fire to others in exchange for something else would have been the most efficient way to deal with this problem, if not the only way.

Ofek makes several observations in support of his claim that are important to my argument. Fires that must burn continually use up lots of fuel relative to the usable energy they produce. Early human fire users for the most part only had access to low quality fuel that had to be gathered frequently, and often had to be transported long distances. Thus, keeping a fire was a costly behaviour relative to other behaviours early humans engaged in. The relative cost of keeping a fire also increased the longer a fire using group stayed in the one location. Caves keep a fire from going out in the rain, but they increase the energy costs associated with travel.

In summary, the literature contains many arguments, lines of evidence and avenues of inquiry that are relevant to my thesis. Those reviewed above will be developed, and to some extent tested, throughout the thesis. They also serve as a basis for the argument of the thesis. In particular, I will expand on the proposals of Gouldsblom (1986, 1992a & b), Ronen (1998), Wrangham (2009), Gowell (2006), Rolland (2004) and Ofek (2001), and relate their insights to current cognitive theory. It is important to remember that explaining the evolution of cognition is a multi disciplinary endeavour. As such, all these different theories and lines of evidence need to be considered.
Chapter Three: The Evidence for Early Human Fire Use

3.1 Introduction

This chapter reviews the direct and indirect evidence for controlled fire use by humans prior to the Late Pleistocene. My aim is to establish that societies of competent fire users existed throughout the Middle Pleistocene. It is not to construct a history of early human fire use; as such histories remain speculative (Klein 1999: 354-355). To make inferences about any prehistoric behaviour, the first step is to establish that hominins were engaging in the behaviour. The aim of this chapter is to present a case that humans have been using fire since at least the beginning of the Middle Pleistocene.

I will focus on localized site evidence that can be interpreted as campfires or hearths, not on intentional bush burning or ‘fire stick farming’, as there is virtually no evidence for this prior to the Holocene (Rolland 2004: 252). Many modern foragers burn wide areas of grassland or bush land to flush out game or clear areas, and for other reasons. This is not to say early humans would not have engaged in controlled bush burning for whatever reason, only that it is very difficult to empirically demonstrate that they did.

I begin by outlining the problems associated with identifying domestic fires, and how archaeologists can overcome these problems. I then review the direct evidence for controlled fire use prior to the Late Pleistocene, and the indirect evidence for Middle Pleistocene fire use from brain evolution, migration into temperate regions and cave occupations. Current evidence suggests fire use was a regular behaviour in some human populations by the start of the Middle Pleistocene, and was universal by the end, although we cannot rule out widespread fire use much earlier than this. I will finish with a discussion of which human species might have been fire users and the general pattern of Middle Pleistocene fire use.

3.2 Identifying Prehistoric Fire Use

Archaeologists trying to identify prehistoric domestic fires must determine if fire was present at a site and if humans were using it (James 1989: 11). This is difficult because the discovery and recognition of burnt
remains is hindered by taphonomic problems related to their preservation (Preece et al. 2007: 1282, Gowlett 2006: 301), and depositional context (Karkanas et al. 2007: 198).

The time depth involved is perhaps the main problem when trying to identify prehistoric fire use. Traces of fire are not likely to survive hundreds of thousands of years. This is a particular concern for sites in the open where the unambiguous signs of hearths, such as lenticular concentrations and charcoal fragments, are not likely to survive (Klein 1999: 344). Non-structured hearths that are neither lined nor encircled with stones are also less likely to leave identifiable traces. Non-structured hearths are common among contemporary and prehistoric hunter-gatherers (Mallot 2007, Sergant et al. 2006). However, they are not likely to leave identifiable traces. Even Mesolithic hearths of this kind can be “barely visible in the soil” (Sergant et al. 2006: 999). Preece et al. (2007: 1282) sum up the situation as follows;

The extreme rarity of Lower Palaeolithic hearths may be due to taphonomic factors, in that burnt bones are susceptible to leaching in acidic environments and ash and charcoal are dispersed readily by water and wind. Unless special factors have favoured the preservation and recognition of hearths, such as incorporation in an actively forming travertine..., it is unlikely that anything other than a few burnt stones will survive in place.

The beginning of the Middle Pleistocene also marks the onset of more extreme climatic fluctuations. Most of the evidence for human activity in northern Europe and Asia during the Early and Middle Pleistocene has been obliterated by continual glaciations. Gowlett points out (2006: 301) that there are very few places in Northern Europe with high potential for preserving evidence for domestic fires. Fluctuations between cool dry and warm wet environments and the changes in sea and lake levels that accompany them have had a similar effect on sites in the open wherever humans lived. It is no surprise that much of the evidence for early human activity, including possible fire use, is found in caves where the chance of preservation is greater (Rolland 2004: 257). Even when evidence for fire can be positively identified the depositional context of the burnt material is often ambiguous in that we
cannot tell how it came to be associated with artifacts, or other material such as faunal remains. When the association between a fire and other evidence is clear, it can still be impossible to discern if the fire was intentional or incidental unless we can positively rule out natural fires as a probable cause.

Given these difficulties, James has argued that all claims for domestic fires prior to the Late Pleistocene are inconclusive (James 1989 *passim*). Despite criticisms (James [Pope] 1989: 18), his concluding suggestions have been widely accepted. We need to reassess all the claims for early human fire use in light of all the available lines of evidence, paying particular attention to the taphonomic processes under which the evidence accumulated (James 1989: 10-11). James does not exclude the possibility of domestic fires prior to the Late Pleistocene. It is only that in some cases natural causes may better explain the evidence for burning at some sites and at others we cannot be certain either way (James 1989: 10-11).

Archaeologists now have a variety of techniques to identify burnt material and establish its geological context. We have reliable methods that can exploit the fact that carbonized organic matter and particles are stable and survive decay (Rolland 2004: 252). These methods include magnetic surveying, magnometer analysis, paleomagnetism, magnetic susceptibility, alternating field demagnetization, isothermal remanent magnetization, paleointensity, remanence coercivity, macroscopic examination, microscopic ash analyses, X-ray diffraction, spectroscopy and thin section micromorphology (Rolland 2004: 252, Bellomo 1993: 525, Shipman et al. 1984: 307). There is also electron spin resonance and thermoluminescence to demonstrate heating (Rolland 2004: 252, Alperson-Afil et al. 2007: 2).

Karkanas et al. have pointed out (2007: 198) that demonstrating regular fire use by humans requires showing that artefacts are indeed burnt and in primary depositional setting, the sediment is composed of ash or its stable derivatives such as siliceous aggregates or wood phytoliths and other material such as clays are burnt as well. We also need to be able to rule out natural causes. Histological and geochemical analysis can tell us the
temperatures materials were burned at, the cause of their discoloration, their depositional context and the original state of carbonized organic materials. By using these methods to compare materials burnt in experimental conditions (Shipman et al. 1984: 307) or contemporary ethnographic contexts (Mallot et al. 2007) with those from archaeological sites we can identify if the later were burned in a grass, bush, peat, stump, coal or domestic fires.

Archaeologists also focus on evidence for high concentrations of ash and charcoal or their stable derivatives, and deeply burnt localized areas when trying to identify domestic fires. These can exhibit delimited localized areas of burning that we expect from domestic fires. They can also contain evidence for large concentrations of ash that are difficult to account for in terms of natural causes. From this evidence we can make reasonable estimates about the size and duration of fires, and their frequency at a particular location. This helps us to identify the probable cause and, if anthropogenic, the degree of control humans had over a fire (Preece et al. 2007: 1281, Gowlett 2006: 303, Schiegl 1996: 778-779).

The spatial relationships and patterned association of materials at archaeological sites also provide important clues as to the presence of a domestic fire. Based on the evidence from ethnography and ethnoarchaeology we know domestic fires leave distinctive spatial patterns that can be discerned from the accumulated refuse associated with hearth related activities (Alperson-Afil et al. 2007: 10-11). These patterns are not likely to result from natural fires and can be used to identify “phantom hearths” (Alperson-Afil et al. 2007: 11) even when direct evidence for concentrations of ash or localized burning is absent (Sergant et al. 2006: 1006). While simple or complex hearth structures provide clear evidence for controlled fire use, evidence for such structures during the Middle Pleistocene is rare and equivocal.

By cross checking these various lines of evidence we can infer in some cases if a fire was natural or anthropogenic. The only necessary criterion when identifying a domestic fire is that we identify fire was present, but this is not in itself sufficient to identify an anthropogenic fire. Once the
presence of fire is established any combination of the criteria discussed above may be sufficient to identify a domestic fire, depending on the context of the site. “The various methods and techniques in use demonstrate the great efforts taken to identify controlled use of fire in archaeological sites” (Alperson-Afil 2006: 2). Since James’s review (1989) many of the sites at issue have been reassessed and new evidence from other sites has come to light.

It should be noted that some scholars insist on “impossibly rigorous standards of evidence” (James [Pope] 1989: 18) to identify domestic fires, such as the presence of well-defined hearths (Klein & Edgar 2002: 157). If we insist on such criteria then we only have direct evidence for domestic fires after 250 kya (Klein & Edgar 2002: 157). However, on the basis of such criteria we would have to reject evidence of domestic fires from many sites dated to the Upper Paleolithic and later, which would be absurd. This could also prevent us from identifying possible early fire use by not considering all the available lines of evidence, including indirect evidence, which may be logically sufficient in itself to infer fire use by early humans. I am following the approach described above that incorporates multiple lines of evidence. This approach is advocated by Klein and Edgar (2002: 157), and in line with that adopted by most archaeologists.

In addition to the direct evidence for domestic fires, indirect evidence can also be used to identify obligate fire users. Evidence for cave occupation, geographic expansion into temperate environments and brain evolution support the inference that Middle Pleistocene humans used fire. From these lines of evidence, we may be able to make a good case that early humans were obligate fire users, without reference to the direct evidence. Caves are not likely to be widely exploited by humans without fire given the increased traveling costs associated with cave occupation and the inhospitable conditions. Living in seasonally or permanently cold temperate climates is difficult for humans without fire. We can infer cooking from the increased metabolic costs associated with growing and maintaining large human brains because cooking was probably the only way to meet these costs.
3.3 The Evidence for Fire Use by Early Humans

3.3.1 Direct Evidence for Domestic Fire

Archaeologists have identified many sites predating the Late Pleistocene with possible evidence for domestic fire (James 1989, Rolland 2004, Karkanas et al. 2007, Yeshurun et al. 2007, Alperson-Afil 2008). In this section I review the direct evidence used to support and refute claims of controlled fire use by early humans, focusing on Middle Pleistocene sites dating to between 800 – 200 kya. For the sake of brevity I will be selective, focusing on those sites with compelling evidence for competent fire use.

There are several Early Pleistocene sites with possible evidence for domestic fires (James 1989: 9-11, Rolland 2004: 255). At these sites it is hard to tell if the fire was anthropogenic or not. Swartkrans (Pickering et al. 2008: 42) and Koobi Fora (Bellomo 1994: 17) in Africa provide perhaps the best evidence for controlled fire use prior to the Middle Pleistocene. Bellomo has argued (1994: 17) that the evidence for domestic fire at Koobi Fora FJj 20 Main is unequivocal, and Pickering et al. have pointed out (2008: 42) that the case for controlled fire use at Swartkrans based on the histological, chemical and spatial evidence is compelling.

The Early Pleistocene sites with possible evidence for domestic fire are tabled in Appendix One. While this evidence is important it is difficult to make grounded inferences about controlled fire use from it. Even if we accept that the evidence of burning from these sites is anthropogenic, they tell us little about how widespread fire use may have been, the kind of fires these people may have kept, or if we are dealing with occasional or regular fire use. The case for controlled fire use by Early Pleistocene humans is primarily based on indirect evidence (Wrangham 2009: 88-89).

Widespread fire use by humans after 200 kya is no longer a controversial issue (Roebroeks & Villa 2011: 5211). Klein points out that “Unequivocal hearths are commonplace in Middle Paleolithic (Mousterian) sites postdating 200 ky ago…” (1999: 238). Therefore, we need not consider the many sites with evidence for domestic fire from the later period of the
Middle Pleistocene. James also lists the evidence from Zhoukoudian, Orgnac and the Hoxne (Beeches Pit) as questionable (James 1989: 9-11). However, further analysis of these sites suggests fire use by humans as the most likely explanation for the burned materials uncovered.

This leaves fifteen sites referred to by James dating to between 800 – 200 kya with evidence for fire that cannot be positively attributed to humans. To these sites we can add others that have come to light since James’ review with similarly suggestive, but yet to be confirmed, evidence of domestic fire (Rolland 2004: 256-257). The suggestion of fire use at these sites is based on preliminary investigations and further analysis is required to positively identify human fire use. Sites dating to between 800 – 200 kya with suggestive evidence of domestic fire are tabled in Appendix Two. My review of the direct evidence will focus on Middle Pleistocene sites dating to between 800 – 200 kya with compelling evidence for fire use. These are listed below. Further details of these sites, excluding Zhoukoudian and Qesem Cave, are provided in Appendix Three.

**Gesher Benot Ya’aqov**

Gesher Benot Ya’aqov in Israel is the earliest site with clear evidence for controlled fire use extending over a 100,000 year period at the beginning of the Middle Pleistocene. The evidence for burning at Gesher Benot Ya’aqov includes burned wood, grains and fruits, charcoal fragments and burned flint artifacts including spatially clustered microartefacts (Alperson-Afil el al. 2007: 1). Alperson-Afil points out that the environmental conditions at Gesher Benot Ya’aqov were not conducive to naturally occurring fires based on what we know about fire ecologies (2008: 1737). Not only would “exceptional circumstances” have been necessary for a natural fire to have burnt the materials at Gesher Benot Ya’aqov, they would have had to occur repeatedly, which is highly improbable (Alperson-Afil 2008: 1737). If such recurrent natural fires did occur at Gesher Benot Ya’aqov we would expect a high frequency of burnt materials. “However less than 1% of the large wood segments and less than 2% of the smaller botanical remains are burned” (Alperson-Afil 2008: 1737).
<table>
<thead>
<tr>
<th>Site</th>
<th>Age</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gesher Benot Ya’aqov, Israel</td>
<td>Continual fire use evident in Layer 11-6 from levels 1 through 7 between 800 - 700 kya</td>
<td>Alperson-Afil 2008</td>
</tr>
<tr>
<td>Zhoukoudian, China</td>
<td>Fire use evident at Locality 1 Layer 10 dating to between 780 - 680 kya, or 500 - 400 kya</td>
<td>Shen et al. 2009, Rolland 2004, Boaz et al. 2004</td>
</tr>
<tr>
<td>Beeches Pit, East Anglia</td>
<td>Continual fire use evident in area AH from around 400 to 350 kya</td>
<td>Preece et al. 2007, 2006, Gowlett 2006</td>
</tr>
<tr>
<td>Schöningen, Germany</td>
<td>Fire use evident in horizon 13 levels 11-4 at around 400 kya</td>
<td>Thieme 2005</td>
</tr>
<tr>
<td>Qesem Cave, Israel</td>
<td>Continual fire use evident in the lower sequence from around 400 to 200 kya</td>
<td>Karkanas et al. 2007</td>
</tr>
<tr>
<td>Bilzingsleben, Germany</td>
<td>Fire use evident at around 370 kya</td>
<td>Mania &amp; Mania 2005</td>
</tr>
<tr>
<td>Orgnac 3, France</td>
<td>Fire use evident in levels 2 and 6 at around 300 kya</td>
<td>Moncel et al. 2005</td>
</tr>
<tr>
<td>Menez-Dregan 1, France</td>
<td>Fire use evident in Layers 5c and 5e dated to around 200 kya, and in Layers 7 and 9. The date range of these older layers is uncertain, although Layer 9 may date to 400 kya.</td>
<td>Mercier et al. 2004, Monnier et al. 1994</td>
</tr>
<tr>
<td>Hayonim Cave, Israel</td>
<td>Continual fire use evident throughout the Mousterian sequence from Layer F beginning around 250 kya.</td>
<td>Weiner et al. 2002</td>
</tr>
<tr>
<td>Bolomor Cave, Spain</td>
<td>Continual fire use evident from Level XIV around 230 kya</td>
<td>Peris et al. 2010</td>
</tr>
<tr>
<td>Misliya Cave, Israel</td>
<td>Fire use evident in the Upper Terrace around 200 kya</td>
<td>Yeshurun et al. 2007</td>
</tr>
</tbody>
</table>

*Table 3* Middle Pleistocene sites dated to 800 – 200 kya with compelling evidence for domestic fire.

We can also rule out peat or volcanic fires based on the stratigraphic sequence at Gesher Benot Ya’aqov (Alperson-Afil et al. 2007: 10), and underground stump fires could not have reached the temperatures of burning
indicated by the thermoluminescence analysis (Alperson-Afil 2008: 1737). Thus, a natural explanation for the continued presence of fire at this site is highly unlikely.

The clearest evidence for domestic fires at Gesher Benot Ya’aqov is the spatial distribution of the microartefacts. While stump fires may leave localized burnt areas of earth, natural fires do not leave spatially associated radial distributions of burnt materials, whereas human activity around a hearth commonly does (Vaquero & Pasto 2001: 1209-1210, Sergant 2006: 999-1006). Alperson-Afil and colleagues have demonstrated through a detailed analysis of the spatial patterning of burnt material at Gesher Benot Ya’aqov that the pattern associated with human activity around a domestic fire occurs repeatedly at this site (Alperson-Afil & Goern-Inbar 2010 passim, Alperson et al. 2007: 7-12, Alperson-Afil 2008: 1736-1737).

Gesher Benot Ya’aqov is important for several reasons. First, it places controlled fire use some 300 thousand years earlier than the 500 kya date previously accepted by many archaeologists. Second, it suggests Homo erectus had the cognitive capacity to engage in this behaviour. Finally, it tells us that we are not dealing with occasional fire use, but an ongoing cultural tradition. However, we cannot conclude from this evidence that these humans could make fire as proposed by Alperson-Afil (2008: 1737). Although the continuity of fire use at this site may imply access to ignition technologies, fire making was not necessarily required to produce the pattern of controlled fire use evident at Gesher Benot Ya’aqov.

Zhoukoudian Locality 1

The Zhoukoudian Locality 1 cave site in China is renowned for its high concentration of hominid fossils. The evidence for fire use is controversial because the depositional context of the materials uncovered is very difficult to interpret. While traces of fire have certainly been found in association with Homo erectus remains and artifacts at Zhoukoudian (Boas et al. 2004), the hypothesis for controlled fire use by humans at this site has
been challenged. Rolland summarizes the argument against domestic fires at Zhoukoudian as follows (Rolland 2004: 266).

First, bones modified by humans were most likely transported to the cave by carnivores. Second, a lack of ash and charcoal leaves the evidence for controlled fire use ambiguous, lending to an explanation of *in situ* guano combustion or intrusive bushfires as probable alternatives. Third, the tools found at Zhoukoudian suggest a rudimentary and expedient lithic technology, which may suggest these humans lacked the required degree of cognition to keep fires. Fourth, the *Homo erectus* specimens were probably transported to the cave by carnivores (Rolland 2004: 266).

However, Rolland counters these arguments and offers others in favour of controlled fire use at Zhoukoudian (2004: 266-270). His argument is summarized below. The evidence for fire at Zhoukoudian includes burnt redbud bush fragments, scattered charcoals, burnt ostrich egg shells, charred or calcinated animal bones, burnt flakes and implements (including a hammerstone) and burnt hackberry shells. It is unlikely that all of these items were introduced into the cave by ways other than human action. For example, the physical state of the hackberry shells “rules out any but human processing” (Rolland 2004: 267). This suggests humans were occupying the cave, not just being dragged their by carnivores, and can be directly associated with the burnt materials.

The habitat at the time of occupation was not conducive to naturally occurring bushfires that must have regularly swept into the cave to account for the amount of burned materials. The damp cave environment and the lack of guano and phosphate traces would also rule out *in situ* combustion. Macromorphological analysis of the cave sediments does not suggest the necessary high energy water activity required to transport the accumulated artifacts, which themselves show no signs of transport abrasion. Analysis of the artifacts from this and other contemporary Middle Pleistocene sites also refutes the notion of rudimentary technical skills that may imply fire use was beyond the capacities of these humans. Finally, as the average winter
temperatures hovered around -4° to -7° centigrade, dropping as low as -10° around 500 kya at Zhoukoudian, survival would have been precarious for humans without fire.

On the basis of this and other evidence Rolland argues that humans indeed occupied Zhoukoudian at times and that these occupations included efficient repertoires of fire use (2004: 269). Boas et al., who have conducted the most detailed taphonomic analysis of the Zhoukoudian data, also support this view suggesting that the “Contextual relationships … support a model of transient hominid scavenging aided by the use of fire at … Zhoukoudian Locality 1” (2004: 519-520).

**Beeches Pit**

The site at Beeches Pit in West Stow, East Anglia has clear evidence of burning in the form of burnt flints, dark fills with reddened adjacent sediments and many charred or calcinated small vertebrate bones (Preece et al. 2007: 1281). This site has been dated to 400 kya (Preece et al. 2007: 1252). Evidence in favour of natural burning is the high frequency of burnt small invertebrate bones that suggests random burning, and the localized burnt areas could have resulted from stump fires (Preece et al. 2007: 1252). Despite this, the case for controlled fire use at Beeches Pit is compelling.

Preece et al. summarize the case for domestic fire at Beeches Pit as follows (Preece et al. 2007: 1281-1282). First, the greatest concentrations of artifacts are coincident with the areas of burning. Second, areas of intense burning are restricted to shallow depressions, two of which seem to overlap, which “implies a sequence of burning at discreet locations” (Preece et al. 2007: 1281). A refit analysis of the lithic material at Beeches Pit has shown that burnt flakes join together with unburnt flakes, which is suggestive of fires side knapping (Gowlett 2006: 304). This suggests that the fire was very localized and contemporary with human activity. The localization, distribution and intensity of the fires at Beeches Pit would seem to rule out either natural bushfires or stump fires as explanations.
Third, the spatial distribution of the artifacts centers on the burnt areas in a manner typical of domestic fire use (Preece et al. 2007: 1281-1282). Fourth, three different stratigraphic horizons have evidence for burning events, “indicating recurrent fire-use over long periods of the interglacial and into the ensuing cold period” (Preece et al. 2007: 1282). Finally, X-ray diffraction analysis has demonstrated that some of the burnt materials from Beeches Pit were heated at temperatures never reached by grassfires or smoldering tree stumps, and rarely in forest fires (Preece et al. 2007: 1282).

Schöningen and Bilzingsleben

The Middle Pleistocene sites of Schöningen and Bilzingsleben in Germany are correlated with the same stratigraphic travertine sequence and climatic cycles (Thieme 2005: 117). The exceptional preservation quality at these sites has resulted in an impressive array of artifacts. Schöningen 13 Levels 11 – 4 have yielded the famous 400,000 years old wooden hunting spears (Thieme 2005: 123-124). At Bilzingsleben there is evidence for living and working structures and an intentionally marked bone suggestive of external symbolic representation (Mania & Mania 2005: 101, 111). Both sites have also yielded clear evidence of fire use around 400 kya.

The four hearths identified in the Schöningen 13 horizon have characteristically changed the sediment below the find layer. In the hearth areas themselves heat has turned the sediment red and there is evidence of ancient shrinking and drying cracks (Thieme 2005: 127). Further evidence of an intentionally fashioned wooden tool charred at one end is suggestive of fire use. The uneven burning and lack of wood in the immediate vicinity of the site suggest the charring is related to human use, rather than natural fire (Thieme 2005: 125). The depositional context of this artifact and the carbonized traces evident “clearly suggest a direct functional connection with the hearths” (Thieme 2005: 125).

The hearths at Bilzingsleben are identified by concentrations of charcoal and burned stone, and are located in what appear to be settlement structures (Mania & Mania 2005: 100). The spatial relationship of burned
materials, artifacts and human activities strongly suggests fire use. For example a heated block of travertine seems to have been intentionally placed under a travertine anvil (Mania & Mania 2005: 109). The humans living at this site also had to protect themselves from the unfavorable environmental conditions, and the evidence clearly shows that they were able to achieve this by cultural means such as fire use and clothing (Mania & Mania 2005: 103).

**Qesem Cave**

The evidence for domestic fire at Qesem cave comes in the form of large amounts of wood ash, burnt bones and even a possible stone lined hearth (Karkanas et al. 2007: 207). Through a detailed analysis of the macroscopic and isotope evidence, and a combination of macroscopic and microscopic criteria Karkanas et al. reach the following conclusions (2007: 207). There is no evidence for natural fires at this site, or that the burnt material was deposited in the cave after being burnt. The ash remains are not the product of few events; they are composed of completely combusted wood and represent *in situ* burning episodes in their primary depositional context. Mineralogical transformations of calcinated bone found at this site could only have occurred at temperatures reached and maintained by campfires (Karkanas et al. 2007: 207).

The burnt remains are found in clear association with hominin activities such as butchering and stone tool production (Karkanas et al. 2007: 198). Karkanas et al. conclude (2007: 207) that the humans who occupied the upper sequence at Qesem Cave clearly used fire extensively and repeatedly between roughly 400 and 200 kya. Traces of fire are also evident in the lower stratigraphic sequence. However, the frequent use of fire by humans in these older layers is yet to be demonstrated (Karkanas et al. 2007: 208).

**Orgnac 3 and Menez Dregn 1**

Orgnac 3 and Menez-Dregan 1 are two of the oldest sites in France with evidence of fire use. At Orgnac 3 evidence for fire use is found in levels 6 and 2 dating to around 300 kya. Concentrations of burnt bones around which activities were conducted can be interpreted as hearths or areas of
burnt waste at both levels (Moncel et al. 2005: 1296). The association of burnt remains with human activities, such as retouching tools and consuming meat, suggest the hearths served a focus of activity and probably rules out natural fire as the origin of burning (Moncel et al. 2005: 1298).

Menez-Dregan 1 is notable for two structured hearths evident in layers 5c and 5e (Monnier et al. 1994: 157). Although, these were originally dated to around 400 kya (Monnier et al. 1994: 157), this date has now been revised to between 186 – 245 kya (Mercier et al. 2005: 260). Many charcoal fragments associated with human activities in layers 7 and 9 are probably the vestiges of hearths (Mercier et al. 2005: 254). While the age of these older layers is still uncertain, layer 9 could be around 400 kya (Mercier et al. 2005: 254).

**Hayonim Cave**

At Hayonim Cave, Israel there is clear evidence of fire use throughout the Mousterian layers from around 250 – 100 kya (Weiner et al 2002: 1291). The many hearths can be identified by concentrations of sediment derived mainly from ash, and their distinctive round or lens shape when viewed in plain or section respectively (Weiner et al 2002: 1300). Although many of these are younger than 200 kya, the lower horizons of layer E, and Layer F, dating to between 200 – 250 kya have evidence of fire use.

**Bolomor Cave**

Bolomor Cave in Valencia Spain has clear evidence of controlled and reiterative fire use from around 230 kya in level XIII to around 120 kya in level II (Peris et al. 2010). The evidence for structured hearths or combustion structures is in the primary depositional context. The hearth areas have thermally altered the sediments that are clearly delimited from the surrounding soils, and are clearly associated with human activity and burnt archaeological remains. Bolomor Cave is currently the oldest site in southern Europe with clear evidence of controlled fire use (Peris et al. 2010).

Bolomor Cave has also yielded evidence for the diets of humans who occupied this site towards the end of the Middle Pleistocene. Evidence for the
cooking and consumption of tortoises has been uncovered in Level IV (Blasco 2008). Evidence for the cooking and consuming birds is evident in Level XI (Blasco & Peris 2009).

**Misliya Cave, Israel**

Evidence for fire use at Misliya Cave in Israel dating to around 200 kya is abundant. Traces of fire use are attested to in several sections by grey horizons that appear in the breccia. The abundant burnt bones and flints, microscopic pieces of charcoal and calcite that may have derived from ash are concentrated in the grey horizons. These are most likely poorly preserved hearths. The burnt materials were uncovered *in situ* and in direct relationship with human activity.⁹ There is also evidence for a well defined hearth composed of spatially concentrated black and grey ash lenses that are distinct from the surrounding brown sediments (Yeshurun et al. 2007: 659).

In summary, these few sites may not seem sufficient to infer widespread fire use throughout the Middle Pleistocene. However, we need to consider the following conditions. First, only a minute percentage of the evidence for prehistoric human activity survives. We have only recovered a minute percentage of this evidence, and from this, evidence of fire use is not likely to survive. Despite this we now have the sites listed above with compelling evidence for competent use, and many other Middle Pleistocene sites with suggestive evidence.

Second, only a few sites with reported evidence have undergone the kind of detailed analysis required to distinguish natural from anthropogenic fire. As more sites come to light and undergo more detailed analysis I predict the hypothesis that Middle Pleistocene humans were competent fire users will be further confirmed. This has been happening since the time of James’ review (1989) some twenty years ago, and there is nothing to suggest this trend will not continue.

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⁹ This information is provided by the Mysliya Cave Project website page on the human use of fire. Accessed 02/12/2010. [http://misliya.haifa.ac.il/archaeology/fire/fire.html](http://misliya.haifa.ac.il/archaeology/fire/fire.html)
Third, at some of the sites with compelling evidence for fire use, we also have evidence for continued fire use over many thousands of years. Clearly we are not dealing with instances of opportunistic or passive fire use in these cases. All things considered, the case for Middle Pleistocene fire use based on the direct evidence is strong. Also, we have other reasons for thinking the fire use was more widespread than the direct evidence can tell us.

3.3.2 Indirect Evidence for Domestic fire

I will now turn to the indirect evidence for fire use by Middle Pleistocene humans. I will focus on cave use, the consequences of geographic expansion and the increased metabolic demands of Middle Pleistocene humans. Increasing cave occupation by humans of the Early and Middle Pleistocene implies fire use. Rolland notes (Rolland 2004: 257) that evidence for human activity in caves increased significantly during the Middle Pleistocene. Caves are not pleasant places for humans without fire to live being constantly cool, damp and dark, and frequented by dangerous animals (Rolland 2004: 258). They are “places in which we would not expect to find even the least neurologically developed representatives of our genus unless they used fire” (James [Lewis] 1989: 15). They are also impractical from an economic perspective given that cave users incur increased travel costs relative to individuals living closer to resources (Ofek 2001: 164-165).

Caves and rock shelters may have provided early humans with temporary shelter from the elements, but permanent residency may have required fire to make cave environments habitable and safe for humans. Using caves to keep fires and fuel dry may also have been important to the evolutionary stability of controlled fire use prior to the invention of fire making (Ofek 2001: 164-165). The increasing frequency of evidence for cave use and fire use during the Middle Pleistocene seems to be correlated (Rolland 2004: 257).

Expansion into northern Europe and Asia implies controlled fire use. Fire was probably necessary for humans to permanently occupy temperate latitudes beyond 40°. Klein and Edgar point out that humans occupied
environments in Northern China and Europe “where fire would have been more than a luxury” (2002: 157). Mania & Mania suggest that “We can safely…assume…Homo erectus did not come as a naked savage into these regions” (2005: 103). Dennell has argued that humans probably did not permanently live beyond 40° latitudes before 500 kya, with any earlier incursions restricted to warm interglacial periods (2004: 226). However, even during warmer interglacial conditions winter temperatures could still have dropped to uncomfortable levels, and fire also improves thermoregulation at night. Of the sites listed above, those in the United Kingdom, France and Germany are above 40°.

Humans living in temperate regions had to contend with seasonally reduced hours of daylight no matter what the temperature. Early humans, like all diurnal animals, must meet their daily subsistence needs and conduct any other necessary activities during daylight hours. “Day length is an important ecological constraint on an individual’s behavioural options” (Hill et al. 2003: 283), and during winter early humans had less time to meet their needs.

When the ambient winter temperature was cool or cold Middle Pleistocene humans had to contend with the increased metabolic cost associated with thermoregulation (Hill et al. 2003: 283). Fire may have been necessary for tropically adapted hominins to survive, by allowing them to conduct nocturnal activities that would otherwise be impossible and by reducing the cost of thermoregulation. Early humans may have been able to survive at temperate latitudes during warm interglacial periods and during seasonally migrations north without fire. However, permanent occupancy probably required the use of fire.

Human brain evolution may also provide indirect evidence for the widespread control of fire by humans prior to the Middle Pleistocene. Our big brains are metabolically expensive to grow and maintain. Aiello and Wheeler have argued (1995: 199-200) that to evolve big brains there had to be a reduction in the metabolic cost of some other organs. They propose that a reduction in gut size most probably allowed for the evolution of larger brains
in hominins, and this required a substantial overall improvement in diet quality (1995: 219). Wrangham argues that such an improvement would have required cooking (Wrangham 2009, Wrangham & Conklin-Brittain 2003, Wrangham et al. 1999). If it did, then cooking, and by implication controlled fire use, needed to be established in human populations by the start of the Middle Pleistocene if not earlier.

The fossil record indicates that human brain size has increased rapidly, from the australopiths to early *Homo* between 3 and 2.5 mya, from early *Homo* to the *Homo erectus* between 2.5 and 1.5 mya, and from erectus to the Neanderthals and *Homo sapiens* between 750 and 200 kya (Schoenemann 2006). This last increase is the most impressive as it is not associated with any apparent major behavioural change or increase in body size as are the first two (Calvin 2004: 45). Controlled fire use could well have provided both the complex behavioural change that selected for larger brains and the means to meet the metabolic cost by eating cooked foods.

An elegant explanation for this last increase would be that *Homo erectus* populations began using fire around one million years ago. The cognitive demands of fire use, and other behaviours, selected for larger brains, the metabolic cost of which could now be met by eating cooked foods. All things being equal, smaller brains will be selected (Schoenemann 2006: 391). Fire use could have provided both a selective context and removed the evolutionary constrains required for relatively large brains to evolve. This assumes that earlier increases in brain size can be attributed to an improved, but still raw diet.

However, Wrangham has argued (Wrangham 2009 *passim*) that early humans with modern human body proportions and relatively large brains could not have survived without cooking their food. *Homo erectus* and later hominins have comparatively smaller guts, smaller mouths, weaker jaws and larger brains than earlier hominins and nonhuman apes. Our small guts struggle to extract enough nutrients from raw foods to meet our metabolic needs. Our mouth and jaws are not designed to process large quantities of raw
foods. If early humans were consuming more raw meat and underground storage organs, they would have spent most of their time chewing. As Wrangham and colleagues argue convincingly (Wrangham 2009: 1-53, Wrangham & Carmody 2010 passim), we seem to be evolved for eating cooked food.

Some humans today survive on a raw food diet as a matter of personal choice. These humans have access to a wide range of high quality unprocessed and processed foods that early humans did not. Still, raw foodists today struggle to maintain energy requirements, and can suffer from impaired reproductive function (Wrangham & Conklin-Brittain 2003: 35). Preliminary findings suggest that cooking increases the net energy value of food (Carmody & Wrangham 2009: 388). Early humans did not have access to modern amenities and processing techniques, and lived as mobile foragers. No modern human foragers have ever been known to live without cooking (Wrangham & Conklin-Brittain 2003: 35). Like contemporary and prehistoric modern hunter-gatherer groups, early humans would have experienced seasonal or contingent food shortages (Jenike 2001: 216). We have no reason to think early humans were better able to meet their energy demands than modern foragers. Experimental evidence consistently suggests that humans with comparable brain size and metabolism to modern humans who were living as foragers could not have survived without cooking.10

If the digestive system and metabolic costs of Homo erectus were similar to modern humans, as fossil evidence suggests they were, then they may also have struggled to meet their nutritional needs on a diet of raw food only. It is very unlikely that the large brained humans of the Middle Pleistocene could have evolved, let alone survived, on a diet of only raw food. The ‘Happy Cow compassionate eating guide’ tells us that although a 100% raw food diet is “the only true path”, most raw foodists can manage only 75%.11

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The cooking hypothesis argues that the modern body physiology associated with the evolutionary emergence of *Homo erectus* is the result of eating cooked foods. This entails that controlled fire use was established in the population of hominins from which this taxon evolved, and that all *Homo erectus* and her large brained decedents were obligate fire users. This would push the accepted date for controlled fire use back to 2 mya or even earlier.

### 3.4 Who Used fire?

At many Early and Middle Pleistocene archaeological sites we have no associated human fossils. Even where we do, it is difficult to say which species of human was responsible for a domestic fire, or artifacts. This is because paleoanthropologists are undecided as to how many species are represented in the hominid fossil record. If human evolution was continuous and largely intraspecific, as argued by Brauer (2008: 34-35), then maybe only two species were fire users, *Homo erectus* and *Homo sapiens* and an unspecified number of subspecies. On the basis of the cooking hypothesis we could include the immediate predecessor of *Homo erectus*. This may have been *Homo habilis* or *Homo rudolfensis*, or a species for which we have no fossil evidence.

Alternatively, if human evolution during this time was punctuated by several speciation events, as argued by Rightmire (2008: 19-20), then we may be dealing with as many as six different human species excluding early *Homo; Homo erectus, Homo antecessor, Homo heidelbergensis, Homo rhodesiensis, Homo neanderthalensis* and *Homo sapiens*. If this were the case, then at least two and possibly four species could have existed at any one time. In short, identifying who is responsible for any given domestic fire depends on how you choose to classify the fossil specimens.

We are probably a different species from the Neanderthals given the morphological and genetic differences between them and us. The fossil evidence suggests we shared a common ancestor with the Neanderthals sometime between 400 and 800 kya (Finlayson 2009: 106-107). Recent estimates based on a complete sequence of a Neanderthal genome places the
divergence between 270 and 440 kya (Green et al. 2010: 718). However, the fossil evidence does not support the late date (Finlayson 2009: 106-107). The fossil evidence suggests the common ancestor was *Homo erectus* or a species derived from her like *Homo heidelbergensis*. For the sake of the argument I am presenting we need only recognize *Homo erectus, Homo neanderthalensis* and *Homo sapiens* with a species or sub-species leading to either the last two, *Homo heidelbergensis* and *Homo rodesiensis*, in Europe and Africa respectively. Current evidence suggests these last four species and late *Homo erectus* were probably obligate fire users.

Based on the evidence for controlled fire use and this brief hominid taxonomy we can make the following observations regarding which humans could control fire prior to the Late Pleistocene. Controlled fire use is not restricted to a single human species or subspecies. Domestic fires appear well before *Homo sapiens* diverged from their predecessors around 400 - 200 kya (Green et al. 2010: 718). It is very likely that both *Homo heidelbergensis* and *Homo rodesiensis* were fire users, given they are implicated in evolution of larger brains in both Europe and Africa respectively. The Neanderthals and early *Homo sapiens* probably inherited fire use from a common ancestor.

The evidence discussed above suggests that *Homo erectus* was the first human species to gain control over fire, or inherited the behaviour from an immediate ancestor. The direct and indirect evidence for competent fire use strongly suggests later *Homo erectus* populations were using fire around the beginning of the Middle Pleistocene and that fire use was a commonplace behaviour by around 400 kya. It is unlikely that human populations without fire survived the Middle Pleistocene if they were competing with fire users.

### 3.5 The Pattern of Early Human Fire Use

This section looks at what the direct evidence tells us about the pattern of early human fire use. I will focus on the size and duration of Middle Pleistocene fires, how frequent fires may have been and the places where evidence for Middle Pleistocene domestic fire is found. Some Middle Pleistocene domestic fires appear to have burned continuously or repeatedly
over long durations, and were relatively large, about one meter in diameter (Gowlett 2006: 304). Gowlett has suggested these features seem common at many Middle Pleistocene sites (2006: 304), and may represent a pattern of fire use that continues into the Late Pleistocene (2006: 306). Evidence for large domestic fires that burned continually may result from taphonomic bias, because evidence for these kind of fires is more likely to survive in the right preservation conditions. The evidence suggests Middle Pleistocene humans could maintain relatively large fires regardless of whether or not they kept more ephemeral ones of different sizes.

Large fires may be a consequence of early humans not being able to make fire. A fire that must burn continually has an optimal size (Ofek 2001: 159). Small fires are inefficient because they have to be constantly fed and are more likely to go out if perturbed by the elements. Very large fires are inefficient because they burn large amounts of fuel (Ofek 2001: 159). A fire also needs to be big enough to service the needs of those using it. While the evidence suggests relatively large fires, I doubt that Middle Pleistocene humans would have kept fires of one meter diameter flaming continually, as this would be very costly in terms of fuel consumption.

The direct evidence suggests frequent domestic fire use in the same locations over long periods at some sites. At Gesher Benot Ya’aqov in Israel there is a continual pattern of fire use over a 100 thousand year period. At later sites, such as Qesem Cave in Israel, evidence for domestic fires spans similarly long durations. This frequency suggests fire use was an established behavioural adaptation in some human populations from the beginning of the Middle Pleistocene. However, we must not assume from this that early humans always stayed at sites for long durations. For example, the hearth deposits at Hayonim Cave indicate repeated short-term combustion episodes, relative to thicker deposits at other sites, suggestive of longer occupations (Albert et al. 2003: 477).

Evidence for domestic fires prior to the Late Pleistocene is found only in channel beds and caves (Gowlett 2006: 306). The better preservation
potential of these environments no doubt biases the fact that we only have evidence for domestic fires in these places. However, these sites are also good places to keep a fire because lakesides and riverbanks are usually resource rich, and caves protect fires from wind and rain. Early humans may have intentionally selected these sites (Gowlett 2006: 306). However, it may have been difficult for early humans to keep fires anywhere else because these sites provide access to resources or protection. However, caves are not necessarily close to all the things you need and open fires are more difficult to protect from rain.

3.6 Summary

Until recently, the direct evidence for controlled fire use by early humans suggested it was an established behavioural adaptation by about 400 kya. On the basis of this evidence Rolland has argued that the emergence of widespread fire use by early humans was a punctuated event occurring between 500 and 400 kya (2004: 270). However, the evidence from Gesher Benot Ya’aqov suggests that populations of fire using humans have existed for around 800 kya.

The indirect evidence seems to support this date, except the evidence for adaptations that suggest humans living between 2.5 and 1.5 mya regularly consumed cooked food. The direct evidence for domestic fires in Africa dated to around 1.5 mya provides some support for this early date. The premises of the cooking hypothesis are potentially testable and may come to stand as sufficient proof for the earlier date. The indirect evidence for cooking, and by implication controlled fire use, suggests it was probably a widespread behaviour prior to the evolution of Homo erectus in Africa around 1.5 mya.

In summary, evidence for domestic fires prior to the Late Pleistocene is difficult to identify. Despite this, archaeologists have been able to identify a relatively high proportion of Middle Pleistocene sites with evidence for controlled fire use by humans. While humans living prior to the Middle Pleistocene may have controlled fire, the direct evidence is uncertain. However, as a species that is biologically adapted to eat cooked foods, early
humans could well have been obligate fire users from around 2 mya. The evolution of brains within the range of modern humans probably could not have occurred without cooking.

Roebroeks and Villa suggest that the simplest explanation for the lack of archealogical evidence for controlled fire use before around 300 - 400 kya is “that there was no habitual fire use prior to this time” (2011: 5212). The fact that sites we would expect to exhibit such evidence do not have evidence for fire use tends to support this claim. It may be the case that some human populations or societies survived without fire before around 200 kya. However, we have good reasons for thinking fire users have existed since at least the beginning of the Middle Pleistocene.

Roebroeks and Villa dismiss the evidence from Gesher Benot Ya’aqov as opportunistic or occasional, not controlled, fire use (2011: 5212). This is not a fair assessment given the evident pattern of fire use spanning 100 ky at this site (Alperson-Afill & Goren-Inbar 2010 *passim*). Roebroeks and Villa are probably overestimating the limits of human tolerance to cold temperatures (2011:5212). Without effective clothing or well insulated shelters fire would almost certainly have been required to survive sub zero temperatures (Gilligan 2007: 106). Finally, the simplest explanation for how early humans met the increased metabolic costs associated with brain evolution during the Middle Pleistocene is that some populations had regular access to cooked food and a fire’s warmth.

The case for competent fire use throughout the Middle Pleistocene is compelling when we consider the direct evidence for domestic fires in conjunction with evidence for cave occupations, human migration during the Middle Pleistocene and human brain evolution. If fire use was a cognitively demanding behaviour, this is highly significant in terms of trying to explain human cognitive evolution, because the cognitive abilities of humans from this period are not well understood.
Chapter Four: The Contexts of Early Human Fire Use

4.1 Introduction

This chapter discusses the environmental, ecological and demographic conditions fire users had to contend with. I will focus on conditions that would have affected their capacity to keep fire, and how conditions differed from one context to another. Several factors would have been important in this respect, such as the size and range of human groups and populations, resource availability, rainfall and climate. These factors affected a fire using group’s capacity to access, provision for, protect and move fire around. They also provide clues as to how difficult or easy different fire related tasks would have been in a given context.

While our knowledge of these conditions is incomplete, we can make some relatively well-grounded observations and approximations about the demographic and environmental constraints fire users had to contend with. These constraints would have affected the kind of problems fire users had to solve, and how they could have solved them. I begin with a discussion of the various environments early humans lived in. I then discuss the demography of Early and Middle Pleistocene humans focusing on population densities, group size and ranges. I then consider the time budgets and social organization of Middle Pleistocene humans and if they kept ‘private’ or ‘communal’ fires. This chapter serves as a point of reference for arguments made later in the thesis. The aim of the chapter is to highlight that fire users overcame a range of different constraints that would have made fire using difficult.

4.2 Early Human Environments

Although paleoenvironmental reconstructions are difficult, we now have a range of proxies that allow us to accurately estimate a region’s climate and landscape at a particular time in the past. From these we are beginning to build up a reasonably precise picture of the kind of environments early humans lived in. The following discussion provides an overview of what the prehistoric climates and ecologies associated with early human fossils tell us about the habitats and distribution of Middle Pleistocene humans.
Pliocene and Early Pleistocene hominins exploited a variety of tropical and subtropical habitats (Elton 2008: 386-387). Middle Pleistocene humans lived in a range of different habitats, including tropical, warm-temperate, temperate and boreal forest, open savannah, wooded savannah, dry woodland, grassland, dry shrubland and tundra (Elton 2008: 387). Early Pleistocene humans may have been restricted to tropical and warm-temperate conditions. Although, Parfitt et al. suggest (2010) humans occupied boreal zones around 780 kya. Current evidence suggests Middle Pleistocene humans did not live in deserts, arctic regions or at high altitudes (Elton 2008: 387). *Homo sapiens* were probably living in Africa (Mellars 2006), the Levant (Hershkovitz et al. 2010) and China (Liu et al. 2010) by around 100 kya.

*Homo erectus* lived in China around the hilly mountain region of Nanjing City. At the time of occupation around 350 kya the low grassland scattered with mires and lakes gave way to mixed forest at higher altitudes. Zhu and Zhang suggest (2000: 215) that the warm-humid, warm-arid and cool-arid conditions would generally have been more conducive to human habitation than those at Zhoukoudian, in that they were not as cold or arid (Zhu & Zhang 2000: 213). A reassessment of the dates for the Zhoukoudian Locality I *Homo erectus* populations has moved the possible time of occupation back to between 680 and 780 kya (Shen et al. 2009: 198). This implies a human presence in northern China during the mild glacial period corresponding to MIS 18 (Shen et al. 2009: 198), meaning these people would have experienced colder winters than we previously thought.

Humans were present in East Anglia during cold and warm phases during the Middle Pleistocene (Parfitt et al. 2010, Rose 2009, Preece et al 2007). Present evidence suggests that these people lived in landscapes that were well vegetated and that they experienced both cool and warm temperate style climates (Rose 2009: 28). Evidence also suggests that humans have lived intermittently on the British land area from at least the beginning of the Middle Pleistocene (Rose 2009: 28). Until recently Boxgrove in West Sussex, dated to about 500 kya, was the oldest British site with evidence for a human presence. The landscape at the time of human occupation at Boxgrove was
wet and well vegetated with summer temperatures similar to today (Holmes et al. 2009: 11). However, the seasonal range of temperature was probably greater with significantly colder winters (Holmes et al. 2009: 7).

Dennell has suggested (2004: 219) that prior to about 600 kya humans were restricted to tropical and sub-tropical regions below 40° latitude, with only intermittent occupation of more northern regions restricted to warm/wet climatic phases. It is only after this time that we have evidence for the occupation of colder temperate regions (Dennell 2004: 219). However, there is now evidence to suggest humans were living in cold climates prior to about 600 kya (Roberts and Grün 2010: 189-190, Parfitt et al. 2010: 229, Shen et al. 2009: 198). In Spain humans would have experienced conditions favourable to their survival. The Early and Middle Pleistocene human occupations at Gran Dolina were during “rather humid” warm periods (Blain et al. 2009: 64). In Africa early humans would have had to contend with frequent climate change leading to profound shifts between open drier conditions and moister ones with greater tree cover (McNabb 2005: 291).

Evidence from the Arabian Peninsula and South Asia indicates human occupations from around 1 mya (Petraglia 2005: 312). The archaeological evidence suggests a human presence persists in these regions from about 780 kya when a widespread dispersal by humans into the Levant and South Asia seems to have occurred (Petraglia 2005: 313-315). Sites in this region were associated with fresh sources of water, however humans living here would have had to cope with increased aridity and monsoonal variability that may have led to population migrations or extinctions early in the Middle Pleistocene (Petraglia 2005: 315). After 500 kya human populations are clearly abundant in Arabia and South Asia with even the harshest environments continually occupied (Petraglia 2005: 313).

Middle Pleistocene humans lived in a range of conditions that would have constrained their capacity to keep fire, such as cool temperate, hot tropical and open environments. In these habitats fire users probably had to contend with constraints, such as low fuel loads, damp conditions, persistent
rain, snow cover, temperatures below zero, extreme heat, and reduced hours of daylight, depending on their particular context. Some humans may have had to deal with all these conditions throughout the course of a year. These conditions would have made fuel gathering, preventing a fire from going out and transporting fire more difficult.

4.3 Early Human Demography

This section discusses aspects of early human demography such as population size and range, and the range, size and mobility of groups. ‘Total population’ refers to the aggregate of individuals with the potential to reproduce (Lycett & Norton 2009: 3). ‘Metapopulation’ similarly refers to a population of partially isolated subpopulations (Premo & Hublin 2008: 33). The ‘effective population’ is the number of individuals actually involved in the reproductive process with each other (Lycett & Norton 2009: 3). I am using the term ‘group’ in reference to a number of proximate individuals who interact on a daily basis. While this is in line with its general sense in the anthropological literature, it differs from its use in population genetics where the term ‘group’ can refer to the total population (Lycett & Norton 2009: 3) or a subpopulation (Premo & Hublin 2008: 33).

Early and Middle Pleistocene human population sizes would have fluctuated according to resource availability and the distribution of habitable environments (Wells & Stock 2007: 198, Premo & Hublin 2009: 36). During glacial periods much of northern Europe and Asia was uninhabitable and resource availability in tropical environments would also have fluctuated according to changes in climate. Evidence suggests human populations in central South Africa during the Early and Middle Pleistocene were higher when the climate was warm and wet, and lower during extended glacial periods (Beaumont & Vogel 2006: 224). Middle Pleistocene human populations of the Solent River / River Stour confluence Southern England were relatively small around 500 and 400 kya, followed by a significant increase around 300 kya (Hosfield 2005: 229-230). While increases and decreases no doubt occurred in total and effective population sizes, scholars tend to think populations were relatively stable over the course of the
The apparent technological and cultural stasis of the Early and Middle Pleistocene relative to later periods may also indicate low population densities and group sizes, rather than a lack of cognitive aptitude as has been proposed. There is evidence that demography constrains the development, diffusion and stability of adaptive technological innovations (Powell et al. 2009: 1298, Lycett & Norton 2009: 4-5, Henrich 2004: 208-209, Shennan 2001: 13-15). Small groups at low population densities distributed across a wide geographical range are more isolated from each other. In smaller groups there are fewer opportunities to learn a new skill because there are fewer skilled practitioners to learn from or imitate. This reduces the probability that an adaptive innovation will be faithfully transmitted within and between groups, because there is less contact and migration between groups, and fewer competent exponents to learn from. Thus, “technological differences…may result from differences in group size and sociality, rather than in genes related to cognitive abilities” (Henrich 2004: 209).

Comparative evidence tends to support the view that demographic, not cognitive constraints explain the pattern of cultural change and stability throughout the Pleistocene and for cognitively modern forages throughout the Holocene (Lycett & Norton 2009, Foley & Lahr 2003 passim). This also helps us to understand why humans with modern cognition are not always associated with the behaviours thought to identify such cognition. Further it explains why the ‘cultural revolution’ of the Upper Palaeolithic, thought to indicate a cognitive revolution, comes early in Africa and is delayed in Australia (Habgood & Franklin 2008 passim). It also helps explain why simpler technologies seem to persist in one region and not others or replace more complex technologies (Foley & Lahr 2003 passim).
We have reason to think that the population densities of early humans including *Homo sapiens* were generally low prior to the Late Pleistocene. *Homo sapiens* in Africa may have reached a very low effective population sizes even during the Late Pleistocene (Mellars 2006: 9383-9384). Although populations of the Upper Palaeolithic in Europe seem consistently higher in terms of density and group size than any previous period, dramatic and sustained increases in the total and effective population sizes of our species are correlated with the advent of agricultural and then industrial societies (Wells & Stock 2007: 201-202).

I now consider the size, range, and mobility of Middle Pleistocene human groups. We can recognise three kinds of groups among modern human foragers, the ethno-linguistic group or ‘regional band’, the local or residential group and foraging parties that split from the local group during the day (Marlowe 2005: 57). In small-scale forager societies a regional group may constitute an effective population. The minimum population size needed for viable breeding is about 175. Late Pleistocene Neanderthals of Crimea probably had regional groups of around 300 (Burke 2006: 517). However, while ethno-linguistic groups may constitute a regional band, the former can be much larger than this with some members never interacting socially (Marlowe 2005: 57). While Middle Pleistocene humans required viable effective populations, we cannot assume these populations constituted ethno-linguistic groups comparable to modern hunter-gatherers.

The local group, in contrast to a regional group, consists of individuals who interact on a daily basis, travel together and sleep together at night. This is the group level that I suggest constituted a ‘fire-using group’. In most modern forager regional groups there is frequent mobility between local groups by individuals, and local groups may come together for periods to exploit seasonally abundant resources or for other reasons. Archaeological resolutions from Middle Pleistocene sites prevent us from making precise estimations of group size at many sites. However, archaeologists have a range of ways to estimate the mobility and size of early human local groups, using both ethnographic and ethnoarchaeological data and theory.
Modern hunter-gatherer groups provide a rough proxy that allows us to set a provisional upper limit on early human group sizes. This is not to suggest that modern foragers can be used to model the cultural or cognitive sophistication of early humans. 30 individuals is the median local group size based on “the largest forager dataset that exists” (Marlowe 2005: 54). If early humans were no better at foraging than modern foragers, lived in similar environments, were highly mobile like modern foragers and lacked the social institutions and technological supports that allow larger than average group sizes, then we have no reason to think Middle Pleistocene groups regularly exceeded 30 individuals. Of course Middle Pleistocene humans living in rich environments or during boom times would have been able to support larger groups, but not for the most part.

The archaeological evidence we do have supports the view that local groups were generally small prior to the Upper Palaeolithic. Evidence from the Middle Palaeolithic site of Tor Faraj in the Levant, dated to about 70 kya, suggests groups of 12-15 individuals occupied the site for short periods of one to two weeks (Henry 2003: 264). A site in Spain provides genetic evidence for a Neanderthal group of 12 individuals (Lalueza-Fox et al. 2011: 250). Sorensen assumes a group size of about 25 for Neanderthals living in northern Europe at the end of the Middle Pleistocene (2009: 1-2). The maximum proposed local group size for Neanderthals living in Crimea is also thought to be about 25 (Burke 2006: 518). The figure of 25 is so consistent with ethnographically known hunter-gatherers that it has been suggested as the optimal group size for the forager mode of production (Burke 2006: 518).

Dunbar has argued that relative neo-cortex size predicts group size in non-human primates and social carnivores (1996: 55-64, 109-120). From this he argues we can predict the group sizes of prehistoric hominins. The brain size of *Homo erectus* for example predicts a group size of about 100-120 individuals (Dunbar 1996: 112-113). This figure “is at odds with the most salient group among foragers, the local group, which has a median population of 30” (Marlowe 2005: 58). It is unlikely early human local groups reached the predicted sizes for several reasons.
There is no archaeological or ethnographic evidence to support this figure. Primates that live in large groups primarily do so for the protection it affords against the risk of predation. While predation was certainly a problem for early humans (Coolidge & Wynn 2006 passim, Hart & Sussman 2009 passim), *Homo erectus* may not have been at the same risk of predation as other primates being larger bodied, more technologically proficient and possibly more cooperative in dealing with predators, and so did not need to live in comparably large groups. Middle Pleistocene humans were in direct competition with some of the large carnivores that preyed on them (Stiner 2002: 4). This implies that they may have developed effective strategies for dealing with the threat of predation other than living in large groups.

Like all top level social predators, Middle Pleistocene humans seem to have lived in small groups widely distributed over large areas (Stiner 2002: 33). The trophic level of Early Pleistocene and more so Middle Pleistocene humans after about 500 kya is not consistent with large groups (Stiner 2002: 33-34). *Homo erectus*, being one of several large predators, seemed to favour open habitats such as grasslands and mixed steppes because these favour large grazing animals (Ciochan & Bettis 2009: 153). Early human technology and social organization was probably simpler than that of modern foragers, so it was unlikely to have supported local groups of over thirty, let alone one hundred and thirty. In the context of human behavioural ecology large group size is an energetically costly strategy that forces modern foragers to engage in a high mobility strategy (Grove 2009: 232).

Middle Pleistocene humans may have lived in social communities of over 100 individuals akin to a regional group of modern human foragers (Dunbar 1996: 120). However, we cannot know the degree, or much about the nature, of social interactions between individuals from different local groups. We have no reason to think local groups were on average larger than around 15 to 30 individuals. Interestingly, large communities of fire users could further increase the demands on social intelligence in terms of monitoring free riders and increased competition for fuel.
4.4 Range and Mobility of Early Humans

The ranges of early human populations and groups would have fluctuated according to resource availability and geographical barriers. By the beginning of the Middle Pleistocene humans were living in Britain, Northern China, Arabia, South East Asia, the Levant, and throughout Africa. We do not know how many effective populations existed at any one time, or if populations had a continuous presence in all these places. The Neanderthals occupied Western Europe through to Siberia in Asia and as far south as the Levant. Recent genetic evidence has extended the known Neanderthal range “at least 2,000 km further to the east than commonly assumed” (Krause et al. 2007: 902). Fabre et al. have proposed (2009: 1) that the Neanderthals were divided into three geographically distinct effective populations.

The range of local groups would have varied according to landscape topology, mobility strategy and resource availability. Archaeological evidence suggests Middle Pleistocene humans generally stayed close to water, food and lithic resources (Gowlett 2006: 306). The ranges of local groups are difficult to estimate from current evidence. However, the transport distance of raw materials provides a rough proxy for the distances local groups may have covered. Coupled with evidence for ‘ephemeral butchering sites’, ‘ephemeral camps’, ‘short-term camps’ and ‘base camps’, and ecological evidence, we can make reasonable estimations of local group ranges (Burke 2006: 514).

Middle Pleistocene humans were certainly capable of procuring resources from remote locations up to 20 km away (Rivals 2009: 337). The average transport distance of raw materials, 10-12 km, for Middle Paleolithic Neanderthals living on the Crimean peninsula from about 45 to 30 kya suggests local groups had a range of 300-450 km² (Burke 2006: 514). However, evidence for raw material being transported 20 km or more during the Middle Pleistocene is rare (Burke 2006: 514), and the transport distances of Acheulean artefacts in African and East Indian populations of Early Pleistocene hominids are low, averaging 3.5 km (Petraglia 2005: 315). However, there is evidence to suggest transport distances increase from 13 to
100 km around 1 mya, and from 100 to 300 km around 130 kya (Marwick 2003: 78).

The duration early humans stayed at one site would have affected their ability to gather fuel. Middle Pleistocene humans were quite capable of long occupations, but often stayed in the one spot for only a few days or weeks. Evidence from Arago Cave in France suggests the mobility of the humans that lived there during the Middle Pleistocene could vary from short one-month stays to occupations lasting one year indicating “all types of settlements…were possible in the Arago Cave” (Rivals 2009: 335-337). The high concentrations of ash at Middle Pleistocene sites, such as Qesem cave, and Late Pleistocene sites, such as Kebara cave, also suggest extended occupations (Berna & Goldberg 2008: 115-116, Albert 2003: 477).

How often and far a group of foragers might move when relocating depends on the group size, the occupation duration and habitat quality (Grove 2009: 225). These three variables determine how quickly and widely a central placed group will exhaust local resources, which in turn conditions how often and how far they must relocate. For modern foragers, exhausting plant resources is the primary reason a residential base is moved (Grove 2009: 224). This may have applied to Homo erectus who we think depended heavily on plant foods. However, this may not apply to all Neanderthals, as they were clearly big game hunters (Kuhn & Stiner 2006 passim, Stiner 2002 passim), and probably consuming higher quantities of meat (Richards & Trinkaus 2009: 16073). This is not to suggest that a Neanderthal diet did not include a wide variety or large amount of plant foods (Henry et al. 2010, Lev et al. 2005).

To gain a perspective on how far early humans may have moved when relocating we can use Binford’s ‘complete radius leapfrog pattern’ of forager movement (Grove 2009: 223). In this model the minimum necessary distance moved between residential sites is equal to twice the foraging radius (Grove 2009: 223). This model is applicable to fire users, given that they operate from home bases (Rolland 2004 passim). From what we know about early
human habitats, and the lithic transport distances of Middle Pleistocene humans, it is reasonable to speculate that they regularly moved 10 to 30 km when relocating. While movements from one patch to another may have been incremental, these ranges and mobility patterns can have negative consequences for fire users in some contexts. For example, if fire had to be moved a long way, accessed from remote places or if fuel loads were widely distributed.

4.5 Early Human Time Budgets

Early humans had to eat, drink, forage, deter or avoid predators, and make stone tools. They also had to compete and bond with other individuals, maintain and monitor social relationships, mate and care for their young. Fire users had to do all these things and fire related tasks. Given the time constraints non-human apes and modern human foragers invariably encounter, it is reasonable to assume early humans did not always have long durations of ‘spare’ time available (Hill 2003: 279). When food is scarce human or primate foragers may spend most of their time searching for food. Primates can spend up to 20% of their time budgets grooming and reductions in available grooming time can destabilise social coherence (Lehmann et al. 2007 passim). The ethnographic and archaeological data consistently suggest seasonal food shortages may have been a universal condition for most forager societies (Jenike 2001: 216). From this it is reasonable to infer that Middle Pleistocene fire users sometimes would have experienced difficulty finding enough time in the day to meet their needs. So time had to be allocated on the basis of priority and individual preference.

Accessing fire, fuel gathering, tending fire, and transporting fire takes time and energy. Given that their fires burned continually, the kind of fuel available to early humans, where they lived and their lifestyle it is reasonable to infer the average day to day cost of keeping fire was relatively significant. Some individuals in the group must have dedicated a considerable amount of time and energy to fire related tasks. Exactly how much depended on how much fuel was gathered each time, the number of gatherers, the quality of fuel, ease of access, time spent searching and how far they travelled.
Fuel gathering would have been more costly relative to other behaviours if early humans did not stockpile, divide their labour or contribute equally to a fire’s upkeep. The relative cost of using fire could have been greatly increased or reduced depending on the way early humans went about fire-related tasks. For example, carrying only small amounts of fuel is less efficient than carrying as much as you can each time you gather fuel. Evidence from forager societies consistently shows that carrying larger loads and making less trips is more efficient even when resources are nearby (Winterhalder 2001: 22). Many individuals can gather more fuel than a few, reducing the overall cost to individuals. Using fire would have required a minimum degree of efficiency and social coordination given the time constraints early humans would have encountered.

4.6 Communal Fires

Middle Pleistocene human groups may have kept ‘communal fires’ that served the needs of all group members, or ‘private fires’ that served one or a few members of a local group. I am assuming that a communal fire scenario was the most probable in the context of Middle Pleistocene fire use for the following reasons. The direct evidence for Middle Pleistocene domestic fires discussed in section 3.5 above supports the view that Middle Pleistocene humans kept communal fires.

Private fires would have been less efficient because they require more fuel and maintenance for about the same return as a communal fire. Private fires would have been socially destabilizing if individuals from the same group were in competition for resources. In contexts where fuel was scarce this would have resulted in social conflicts as individuals tried to dominate fuel resources. Without the kind of prosocial conventions and cognitive supports that govern private fire use in modern forager societies, keeping private fires would have been difficult to coordinate.

A private fire or communal fire is a public good. Ofek has argued that the problem of free riding excludes a system in which individuals can borrow fire for free from other members of their group, and that communal fires
imply levels of altruism that we are not entitled to infer (2001: 159-160). However, communal fires do not necessarily imply unconditional cooperation and private fires can compound the problem of free riding, because free riders would have been harder to monitor. Also, in a communal fire scenario access could have involved costs that Ofek does not consider, because groups were isolated from each other. All things considered communal fires were more probable because they would have been more efficient and less socially destabilizing than private fires.

4.7 Summary and Discussion

Middle Pleistocene fire users lived in a variety of habitats, including relatively treeless savannah and grassland. Some lived in the equatorial and tropical climates of Africa and Asia. Others lived in the mild to cold climates of temperate Europe and Asia. Fire users had to contend with the seasonal variation in rainfall associated with tropical, warm temperate or cool temperate climates. Depending on their context they would have encountered hot dry periods, monsoons, storms, rain, snow or freezing conditions. Those at temperate latitudes experienced relative reductions in daylight hours between the autumn and spring equinox.

The evidence suggests that effective populations of fire users consisted of small local groups similar to many modern foragers. Population densities were for the most part low. There is no evidence to suggest Middle Pleistocene local groups exchanged goods and ideas in the way modern foragers do. Although, Marwick suggests (2003: 78) that the evident increase in the maximum transport distances during the Middle Pleistocene implies exchange networks. From what we know, it is reasonable to infer Middle Pleistocene local groups were often isolated from each other. These environmental and demographic conditions would have made fire keeping more difficult for Middle Pleistocene humans in the following ways.

Fuel was more difficult to procure in open environments than in forested ones because fuel loads are greatly reduced in these environments, and their distribution is patchy. This means fuel would have been harder to
find in grasslands than in forests. However, in well forested regions the cost of moving around and finding food can increase. Fire users in open habitats sometimes would have had to bring in fuel from remote sources, stay close to stands of trees, or frequently relocate as proximate resources were exhausted. Fire users in these habitats would have spent more time and energy keeping up the fuel supply than those in forested habitats. For humans in temperate regions, reductions in daylight hours meant they had less time to gather fuel during the winter months relative to the other seasons. For some Middle Pleistocene humans in temperate climates, snow cover would also have made finding fuel difficult in open or forested habitats.

Depending on where they lived, some Middle Pleistocene humans had to contend with relatively treeless environments. Fuel was more difficult to procure in savannas and grasslands, the preferred habitat of some early humans, than forested locations. Monsoons, seasonally or permanently low ambient temperatures at times below freezing, and seasonal reductions in resources and available daylight, all would have made fuel gathering more difficult. The distribution, availability and quality of fuel would have varied depending on their location and how long they stayed there. At times contact between local groups would have been infrequent if effective populations were widely distributed. All these factors could have effected how fire was accessed, maintained, transported and used in the following ways.

Accessing fire from other human groups would have been more difficult for those groups that were isolated from others for long periods. Small group sizes limit the amount of fuel the group can gather and increases the cost of gathering to individuals. Smaller foraging ranges could have resulted in having to travel beyond the group’s usual range to find fuel or frequent relocations before fuel resources were exhausted.

Caves are less frequent in open grassland environments as are natural windbreaks and shelters, affording humans in these environments less chance of protecting their fires from the elements. Humans living in tropical and subtropical woodland or grassland had to contend with the wet season and even
monsoon conditions for several weeks or months of the year. Seasonal reductions in food availability meant more time spent foraging during these periods, which in turn meant less time available to gather fuel.

Humans living in temperate environments would have encountered seasonal reductions in daylight, and so less time to gather food and fuel. These would sometimes have coincided with temperatures below zero and snow cover for two to three months of the year. For humans living in these conditions, decreased food and fuel availability coincided with a reduction in available gathering time. Most fire using humans wherever they lived had to deal with conditions that at times would have made controlling fire difficult.
Chapter Five: Fire Related Problems

5.1 Introduction

This chapter describes the kind of problems Middle Pleistocene fire users would have encountered when accessing, maintaining and using fire. The aim is to establish grounds for making inferences about behaviour from practical problem solving contexts. It is important to establish the kinds of problems fire users had to solve, before we can investigate how they may have solved them. I begin by proposing that Middle Pleistocene fire users were dependent on fire to survive, but could not make fire. While we do not know this for certain, we have reasons to think this would have been the case during the Middle Pleistocene. I then focus on how fire users accessed fire if they could not make it and argue that natural sources would not have provided a reliable ignition source when one was needed. From this we can infer that Middle Pleistocene fire users probably accessed fire from domestic fires. Accessing fire from other groups would have been difficult if others were not close by or they did not want to allow access.

Maintaining a fire involved provisioning, protecting and transporting fire. Humans who could not make fire would have had to keep their fire burning continually or rely on other individuals to gain access, and fires needed to be big enough to service the needs of those using them. Early human fire users faced two key problems: limited access to high quality fuel and the increasing cost of gathering fuel relative to the time spent at one location. Fire users in the open may have tried to protect their fires from rain. This would have been a problem because the availability of natural shelters is limited, and using natural shelters increases the distances individuals travel relative to those living close to important resources. Moving a fire might have been a problem if fires had to be carried for long distances, because carrying a burning stick or log would not always have been reliable. I will focus on cooking and heating as the primary ways in which fire was used. Cooking involves delaying consumption and increases the potential for food stealing. Using fire for warmth would have involved gathering large quantities of fuel to produce fires that would have provided sufficient heat.
5.2 Obligate Fire Use

Humans using fire regularly to cook or keep warm would come to depend on these benefits as an unintended consequence of fire use (Burton 2009: 42, Wrangham 2009: 89-96, Goudsblom 1992a: 6). These benefits would have had an immediate positive impact on the fitness of fire using humans by enhancing their chance of survival. Evidence from the evolution of human physiological and neurological features, such as small mouths, small guts and large brains, suggests Middle Pleistocene humans depended on regularly eating cooked food to survive (Wrangham 2009 passim). Middle Pleistocene humans living in temperate regions would have struggled to survive cold temperate winters without the aid of fire (Klein & Edgar 2002: 157, Mania & Mania 2005: 103).

‘Extending the day’ may also have had important fitness benefits, if early humans used fire for light to do things after dark (Burton 2009 passim). Humans making the transition from tree to ground sleep may have benefited from fire use if it helped deter predators (Coolidge & Wynn 2006: 5). However, it is difficult to know exactly how these benefits may have improved survival. The general assumption that fire use decreases the risk of predation because animals have a natural fear of fire requires testing.

The Neanderthals and Homo sapiens were evidently obligate fire users, and may well have inherited their fire dependence from a common ancestor existing sometime between 800 – 200 kya. There could have been Middle Pleistocene humans who survived without fire, and those who could get along well enough without it for long durations. This is fine for the fireless until they come into competition with fire users, which ultimately they would have. All else being equal, fire-users would probably out-compete those without fire (Gouldsblom 1986: 522). Ironically, human populations that could survive without fire were probably out competed by those that could not. Today, only fire dependent humans survive. Evidence suggests that populations of fire dependent humans evolved between 800 – 500 kya. However, fire dependence could have occurred much earlier, between 2.5 - 1.5 mya (Wrangham 2009: 96).
Obligate fire users cannot afford to be without fire for long durations, and being without fire was less tolerable in some situations. If the climate was perpetually warm, and lots of high quality raw foods were available, such as ripe fruits and nuts, then losing fire may have been tolerable for an extended period. However, if food was scarce, or required cooking, and cool to cold seasonal temperatures had to be endured, then surviving without fire would have been difficult. In these contexts, being able to access fire and maintain it were critical human adaptations.

5.3 Making Fire

We do not know when fire making was first discovered, or became a regular human behaviour. Why then assume that early fire users could not make fire? The circumstantial evidence against fire making is as follows. Many fires of the Middle Pleistocene were large, burned for long durations and were kept in caves which may imply that extinguishment was to be avoided, which in turn implies they could not make fire (Gowlett 2006: 306). However, this pattern could be explained in other ways, such as big fires were more effective and caves offered shelter in general.

While evidence for fire use goes back to 800 kya, the earliest evidence for fire making, in the form of pyrite ‘strike-a-lights’, comes from Upper Palaeolithic sites in Denmark and Holland (Stapert & Johansen 1999: 765). While absence of evidence is not evidence of absence, as fire making is not a necessary condition for controlled fire use, we are not entitled to infer the former from the latter without evidence. For the same reason continual competent fire use over long durations of prehistoric time, suggestive as it is, cannot stand as evidence for fire making as has been suggested (Alperson-Afil 2008: 1733, Rolland 2004: 267). Rolland may be overstating the case for fire making when he suggests evidence for fire use at Eurasian sites 400 kya “testify unequivocally that Homo mastered regular fire production by this time” (Rolland 2004: 267).

Fire making presupposes a history of controlled fire use, whereby an understanding of fire’s properties and behaviour can be acquired and
accumulated. Given that all inventions go through simple stages before becoming more complex, it is reasonable to infer fire users once existed who had no knowledge of ignition technologies (Ronen 1998: 443). If we deny such a history we must assume humans once existed who could make fire, but not control it. While this is possible it seems counter intuitive. “It is far safer to assume that such a capability was reached only in the course of evolutionary time, after many generations of exposure to the use of fire” (Ofek 2001: 158). No one, to my knowledge has suggested that early humans could make fire before they could maintain it effectively.

None of these reasons allow us to say with certainty that people of the Middle Pleistocene could not make fire. However, my key concern is, was fire use more cognitively demanding without access to ignition technologies. While fire making may reduce cognitive demands because remembering to gather fuel is less critical, overall I would argue fire making is more cognitively demanding, than fire use without ignition technologies. Fire making has been likened procedurally to prepared core technologies, and so may be no more cognitively demanding than these (Nobel & Davidson 1996: 206). I would counter that it is cognitively more complex for several reasons.

Fire making is more like component technologies than flaking procedures (Gamble et al. 2011: 123) in that three or more distinct materials come together to produce the final product. Component tools are generally considered to indicate a significant cognitive advancement over prepared core and bifacial lithic technologies (Wynn 2009: 9544, Ambrose 2001: 1748). Hafted tools are the earliest known compound technology we have evidence for. The earliest hafted tools date to between 300 – 200 kya (Ambrose 2001: 1748). In these tools three components, head, shaft and binding, or bonding agent, come together to produce a spear or axe with similar functional properties to a sharpened stick or hand axe, albeit more efficient and effective.

Fire making adds another level of complexity to that of hafted tools. In fire making, three or four materials come together to produce an element
with totally different material and functional properties than the components that produced it. Producing an element that has different material and functional properties from those that produced it is arguably a conceptual advancement on hafted tools. While fire making may be procedurally similar in some respects to making a hafted tool, conceptually it requires a further level of representation, or even abstraction. Fire making implies representing the effect of the components, not just the components as a single tool, where that effect is itself nothing like the materials that produce it. Representing the form of the final product may be required to produce an Acheulean stone tool (Coolidge & Wynn 2009: 121), and it may not (McPherron 2000: 656).

Fire making is a culturally acquired skill. One does not accidentally become a fire maker. One must infer the causal relationships involved from observed effects, and try to reproduce the desired result. Alternatively, individuals probably had to be explicitly shown what materials to use and what to do. The subtleties of fire making would be difficult to learn through observation and imitation alone without instruction. Noticing that wood friction causes heat, or that rocks can cause sparks, is not sufficient to produce a competent fire maker. Fire making techniques are well documented, and we need not review all the variants of the two basic methods (Perles 1977: 34-41). Rather, I will highlight some of the practical and conceptual problems fire makers needed to overcome.

In stone on stone friction, one of the stones must be pyrite or a related iron and sulphur bearing ore (Stapert & Johansen 1999: 766). In wood on wood friction, it helps if drills and saws are harder than the platform, and you need to cut a groove or channel in the platform so that the embers come into contact with a suitably combustible material. Particular kinds of dung or fungi work best to ignite from sparks or embers, but these must be suitably dry. Implementing the technique involves enacting at least three skills each using different motor actions. These are rubbing or striking, handling the ignited tinder and controlled breathing.
Controlled breathing is an important fire using skill for either fire makers or active fire users, and is implicated in the evolution of speech. MacLarnon and Hewitt have noted an increase in the capacity for controlled breathing as evidenced by the increased levels of thoracic innervation in later human species relative to *Homo erectus*, implying that the last common ancestor of the Neanderthals and *Homo sapiens* had modern human control over breathing (2004: 191, 1999: 358). They suggest that improved control over vocalization as the only evident adaptive advantage this would have conveyed with the obvious implications for language evolution (MacLarnon & Hewitt 2004: 191, 1999: 358). Given that we can now place fire use at around 800 kya, enhanced control over breathing could well have evolved in response to using fire, and co-evolved with improved control over vocalization.

Fire making probably involved direct instruction and practice, without which novice fire makers probably could not produce a flame. It requires differentiating like materials, such as pyrite from stone, hardwood from softwood and highly combustible dungs and fungi from their less combustible counterparts. Fire making is arguably more cognitively demanding than controlled fire use in terms of concept formation, causal reasoning, categorisation and cultural learning. It takes time and effort learning the skill, and maintaining a ready to use fire making kit. From this, it is reasonable to infer the cognitive abilities of fire makers were at least equal to that of competent fire-users who could not make fire. If we accept this, then it is safe to assume that Middle Pleistocene fire users could not make fire.

Although we cannot be sure Middle Pleistocene fire users could not make fire, there is no evidence to suggest they could, and we have good reasons for thinking they could not. If fire making evolved from competent fire use, then it is reasonable to think that the cognitive skills of fire makers were equal to, if not greater than, those of fire users without this skill. Thus, I will work mainly from the premise that early human fire users did not make fire.
5.4 Accessing Fire

It is reasonable to infer that the fires of Middle Pleistocene humans went out on occasion. The alternative was that once a group accessed fire they never let it go out. This was possible in theory. However, there are conditions that could have led to extinguishment, such as neglect, rain or running out of fuel. Middle Pleistocene fire users had to be good at keeping fire going, however I am assuming they were not infallible, and on occasion their fires went out. If this were the case, then accessing fire was critical to the survival of obligate fire users. Humans who could not make fire had two basic means of access: get it from nature or from a domestic source. “The enormity of this requirement is no longer fully appreciated by modern humans within easy reach of matches” (Ofek 2001: 151). The problem for Middle Pleistocene fire users was that natural fires were not an option in most contexts. This means fire users probably had to access fire from other fire users if their fire went out. I will offer reasons why natural fires were not really an option for early humans, and then discuss the problems associated with accessing fire from a domestic fire.

5.4.1 Accessing Fire from Natural Sources

Middle Pleistocene humans could have accessed fire from naturally occurring sources, such as grassfires or forest fires started by lightning strikes. The infrequency and often-concealed context of peat, guano, bamboo, dung and underground stump fires means these sources could not have been exploited with any regularity. Volcanic activity, or fossil fuel fires, would have been similarly infrequent and localised. Depending on where and when they lived, Middle Pleistocene humans could have gone generations without encountering natural sources of this kind. This leaves forest or grass fires ignited by lightning as the most viable natural option.

The return times for fires in a given type of bioregion can serve as a rough proxy for the likelihood Middle Pleistocene humans would encounter a natural fire. Contemporary evidence from fire ecologies suggests the return times for fire in the most fire prone regions varies from one to five years (Yates et al. 2008: 768). In these regions fires occur seasonally, usually for
two to four months of the year (Yates et al. 2008: 768). Humans intentionally, or unintentionally, cause 90% of all wildfires (Yates et al. 2008: 769, Bajocco & Ricotta 2008: 244) with the remaining 10% caused by lightning strikes. Although this means less wildfires prior to humans accidentally or intentionally starting them, these fires would not have been actively put out by humans, and so some would have burned for longer than they might today (Cohen et al. 2007: 68). Wildfires are also relatively localised in any given bioregion during the fire season. In temperate regions with boreal forest the return times for fires is measured in decades and centuries (Angelstam 1998: 595-597).

Given that prehistoric fire regimes were in general similar to those of today, the chance that humans encountered fire in their vicinity when they needed it was low; that it could happen with any regularity is very unlikely. This is not to say humans never encountered or exploited natural fires. However, for those early humans living outside of fire prone regions, naturally occurring fires could not always have provided them with a reliable source of ignition when one was required. Many of the sites with compelling or suggestive evidence for domestic fire are in habitats that would not have been conducive to naturally occurring fires.

Humans living in fire prone regions may have been able to access fire for two to four months of the year. Those living in temperate regions without seasonal fire regimes could have gone decades without encountering a natural fire. It follows that wildfire was only an option for humans living in fire prone regions, for a few months of the year. Furthermore, there was no guarantee that fire would occur near those needing fire at a time when they needed fire. Given that fire users did not know when their fire might go out, the chance of regular fortuitous coincidences of extinguishment and proximate natural fires was remote. We must also consider that fire users

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12 During the many climatic shifts from warm and wet to cool and dry during the Pleistocene, massive long lasting wildfires would have occurred as forested regions gave way to grassland and deserts (Calvin 2002: 3). However these extreme conditions would have been relatively short lived.
were more likely to encounter a natural fire when they did not need fire because they presumably had fire most of the time.

Accessing fire from a natural source would not have been an option for fire users living in the northern regions of Europe and Asia. Those in fire prone regions could have accessed wildfires, but only if their fires went out at the right time of year. If early humans were forced to rely on natural fires the behaviour may not have spread beyond fire prone regions prior to the invention of ignition technologies, as it may have. Even for those in fire prone regions, many months spent without fire would have made survival more difficult.

While observing and interacting with natural fires was no doubt important in the initial stages of domesticating fire (Burton 2009: 34-40), naturally occurring fires would not have been a viable option for most obligate fire users in need of a flame. Once humans came to rely on fire and moved beyond fire prone regions, natural fires ceased to be an option. The problem with naturally occurring fires as a potential source of ignition is that they are infrequent, ephemeral, unpredictable, dangerous and stochastically distributed in any given bioregion.

Wrangham has suggested that early humans may have inadvertently started fires while knapping, providing them with natural fires “again and again” (2009: 192). However, this is unlikely. For sparks to occur one of the stones needs to be pyrite (Stapert & Johansen 1999: 766). Stone tools are rarely, if ever, made from such materials. If worked pyrite was found at Early or Middle Pleistocene sites we might suspect fire making, not just incidental fire starting, but it is not. The earliest evidence for worked pyrite is dated to the Upper Palaeolithic (Stapert & Johansen 1999: 766).

\[13\] It is reasonable to think that migrations by fire users beyond Africa and Tropical Asia could not have occurred until humans developed effective strategies or social systems for accessing fire from other domestic sources.
Gowlett has implied (2006: 307) that fires in temperate regions may have been more common than I have suggested, given a systematic density of around three lightening strikes per square km in temperate regions every year. However, many strikes do not result in fire, especially if the ground is damp or snow covered (Angelstam 1998: 595). They are also stochastic, in that strikes are not evenly distributed throughout the year and across a region, with each square km getting hit three times. In any case, “Most lightening strikes do not cause fires” (James [Lewis] 1989: 15, Caldararo 2002: 142). Date from the Alberta Forest Service Canada suggests the ratio of strikes to fires can vary from 1:1, to 1:1000, or none, depending on the weather, fuel conditions and what is struck during the two months of the year that lightening occurs (Caldararo 2002: 142, James [Lewis] 1989: 15). Grass fires caused by lightening are rare (Caldararo 2002: 142). Early humans may have been aware of the connection between lightening and fire as Gowlett suggests (2006: 307), but they could only use this knowledge if lightening occurred near them and started a fire that lasted some time when they needed fire. If population densities were low and groups widely distributed, the chance any given group will be near a lightening strike that starts a fire decreases further.

In most situations natural fires could not have provided obligate fire users with a reliable ignition source. Evidence suggests the return times for naturally occurring fires is measured in years, decades and centuries. Given fire users could not afford to wait years to regain fire, these frequencies are not sufficient to provide fire users with fire when it was needed. The critical variable is that fire had to be available when a group’s fire went out. In the context of dependent fire use these ‘times of need’ might not have been frequent, further decreasing the probability of fortuitous coincidences of natural fire, and the need to access fire. Appeals to spark fires from tool making or the frequency of lightening strikes are not compelling.

### 5.4.2 Accessing Fire from Domestic Sources

If fire users could not make fire, nor access it from nature when they needed it, then domestic fires would have been the only source available. In a population of fire users, domestic fires would have been more readily
available than natural fires. Middle Pleistocene humans intent on accessing fire from a domestic source faced two main constraints, the proximity of other groups and their willingness to allow access. The more isolated a group was from others the further they had to travel to access fire. For groups beyond the perceptible range of potential fire sources, the only option may have been to wait. The best strategy for groups that were isolated from other groups for long durations was to try and ensure the fire did not go out.

We do not know if relations between early human groups were competitive or congenial, and it is naïve to think it was largely one or the other. Middle Pleistocene hominins may have competed for access to fire, as has been argued by Goudsblom (1986: 522). He suggests that the human monopoly on fire use could be the results of “inter specific elimination struggles” (Goudsblom 1986: 522). In this scenario, Middle Pleistocene humans had to access fire from hostile others. It is difficult to say how likely this scenario was, or how likely it was that it could lead to the universal use of fire in the human genus. If individuals or groups who were more adept at controlling, accessing and defending domestic fires left more offspring than the pyrotechnically challenged, then ‘fire dominant’ groups may have become more numerous and the behaviour would have spread more quickly. This is certainly a possibility if the ‘fire dominant’ groups were more coordinated and consolidated than other groups.

Alternatively, if the ‘fire dominant’ group in an area kept everyone else fireless, and then lost their fire, they would have no way to regain it without fire making skills. In this case, the evolution of controlled fire use may have been sporadic with many false starts before becoming a universal human behaviour. The main problem with a competitive scenario, in which interactions were largely hostile, is the high risk involved. Those with the motivation to raid or defend a domestic fire are those at most risk of injury or death from engaging in these behaviours. As such, the behaviours associated with defending fire, or accessing it by force, could have been selected against. Neighbouring groups are also more likely to share biological relations with each other, who might not have been keen to engage in conflict. Although we
cannot rule out competitive interactions associated with access to fire, it was not the only option available.

Ideally, fire users could have accessed fire from other groups without hostility. Middle Pleistocene humans could have accessed fire from agreeable groups for free, ‘borrowed’ reciprocally from each other, or engaged in some form of exchange. However, a system of totally free access may not have been economically viable, and so not an evolutionary stable strategy. As Ofek has pointed out (2001: 160), so long as maintaining a fire is costly and borrowing is free, this strategy cannot last for long. This is because freeloaders, and the pyrotechnically challenged, can afford to spend less time and effort maintaining their fires, if they can get fire when they need it at little or no cost. This leaves them more time and energy to get on with the everyday business of surviving and reproducing, while still enjoying the benefits of fire, at the expense of those who spend more time and energy making sure their fire did not go out (Ofek 2001: 160). If freeloaders and incompetent fire users left more offspring than competent fire users, the net result will be that no one has fire (Ofek 2001: 160).

Thus, accessing fire from other groups without hostility required a system that did not put fire providers at a disadvantage. Ofek suggests free access was not a viable option for private fire users (2001: 160). However, if Middle Pleistocene humans kept communal fires, and were not close to other groups, accessing fire would have been costly in terms of travel and time spent without fire. In this scenario, donor groups would not be at a disadvantage. It is also possible that access was not frequent because groups were good at keeping their fires burning. Under these conditions freeloaders would not necessarily have been able to gain any advantage, particularly if the cost of access was high.

Middle Pleistocene fire users would mostly have relied on other domestic fires to access fire, given they could not make fire, that natural fires were not an option and that their fires occasionally went out. This involved interacting with other groups. These interactions may have been hostile or
agreeable. Fire cannot be given free if this resulted in competent fire users being at a reproductive disadvantage. If borrowing was not frequent and not unidirectional, then free access could have worked. Some form of reciprocal or mercantile exchange was another option for early human fire users. This will be discussed in Chapter Six below. We cannot know how early fire users went about accessing fire. However, we can be reasonably sure that at times they needed to access fire from a domestic source, or that they could maintain fire indefinitely.

5.5 Maintaining Fire

Without fire making skills, or easy access to fire sources, obligate fire users could have reduced or eliminated the cost of accessing fire, and being without fire, by keeping a fire burning continually. Even when access was relatively cost free, ensuring that fire was always ready when needed involved regular maintenance. Keeping a fire burning involved solving practical problems associated with provisioning, protecting and transporting the fire. This section investigates each of these different behaviours.

As with accessing fire, the ease of maintenance was relative to the ecological and logistical constraints fire using groups encountered. Provisioning would have been more difficult for those living in grasslands than for those living in woodlands, and more difficult at some times of the year. Protecting a fire was easier for those who had access to caves. Transporting fire a short distance was easier than trying to move it a long way, and variations in the terrain made moving a fire more or less difficult.

5.5.1 Provisioning Fire

Fire is a compound reaction that needs fuel, oxygen and a sufficient ignition temperature. Oxygen was not a major issue for early humans lest they smother their own fire. However, providing enough fuel to keep a campfire burning continuously was “never a trivial matter” for prehistoric humans (Ofek 2001: 157). Two constraints would have restricted the capacity of Middle Pleistocene humans to keep up the fuel supply, the limited availability of high quality fuel and the increasing relative cost of gathering fuel.
A fire fed on brushwood, twigwood and grass must be frequently stocked and fed, and is prone to extinguishment (Ofek 2001: 157). Stemwood is a far superior fuel, but was practically unavailable to early humans who lacked logging equipment (Ofek 2001: 157). Large amounts of greenwood produce inefficient smoky fires, and may choke off a small fire. If greenwood were not cured, it would need to be mixed or supplemented with dry wood, or added to a large fire burning at high temperature. The optimal fuel available to Middle Pleistocene fire users would have been deadwood that could be easily picked up, or broken off trees, and carried back to the fire. Small trees and bushes could have been chopped down, and branches chopped off with some effort.

Even if early humans lived in dense woodland or forests they would not always have had easy access to high quality fuel. A fire that must burn continually would have used up large amounts of fuel relative to the usable energy it produced (Ofek 2001: 157). It would soon use up all the proximate fuel with an increasingly larger area being cleared around the fire each day (Ofek 2001: 157). So fuel had to be transported increasingly longer distances each day. Evidence for large hearths at sites such as Beeches Pit and Schöningen suggests large amounts of firewood, 50 to 100 kg per day, were being resourced from remote locations (Gamble et al. 2011: 123). Fuel searches, and fuel gathering, would have taken up more time each day that fire users remained in the same location. For every kilogram of fuel burned that average cost of finding another kilogram in the same vicinity increases. If only low quality fuel was available or used, then gathering enough fuel to sustain the fire could quickly become difficult. Fire users either met their fuel requirements under these circumstances, or frequently relocated to sites where fuel was easier to access.

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14 I am assuming Middle Pleistocene humans did not for the most part use fossil fuels and only had hand held stone choppers, cleavers or axes. The hafted tools that appear late in the Middle Pleistocene and during the Late Pleistocene would not have been much more effective as logging implements than these earlier tools.
Experimental work confirms the economic prediction that increasing the distance travelled each day to find food has negative fitness consequences by decreasing the amount of energy invested in reproduction, repair and maintenance (Pontzer & Kamilar 2009: 192). The travel costs associated with fuel gathering would have been significant when added to food gathering travel costs. Early humans could have started chopping down or off more proximate fuel sources, rather than traveling further each day. However, chopping down local resources is not necessarily more energy efficient than walking further and gathering deadwood. Even in well-vegetated environments, all the easily available proximate fuel will be used up quickly. So either early humans traveled further, started chopping or moved on.

Frequent relocation, or remaining tethered to fuel resources, would have reduced fuel-gathering costs. While some humans may have adopted either of these strategies, premature relocation and restricted site choice may not be adaptive if they take you away from, or limit your access to, food, water and other important resources. The evidence discussed in Chapters Three and Four suggests that early humans were not restricted in this way, which implies Middle Pleistocene fire users could overcome these two constraints.

Fires also have to be tended. At times during the day, and perhaps the night, the fuel supply and fire had to be monitored and stoked, fed or replenished as required. There are different ways fire users could have tended their fires. Someone could stay with the fire, or the fire could have been built up at night, or when it was left unattended. The behavioural implications of these different strategies will be discussed in Chapter Six below.

5.5.2 Protecting Fire

Heavy or persistent rain will douse a campfire in the open, unless it is a very large one. Humans trying to protect an open fire during inclement weather had few options, and little chance of success, without knowing what to do and implementing that knowledge quickly. Early humans may have been able to predict bad weather, but even today meteorology is not an exact
science. Bad weather would often have affected all fires in the open across a wide region.

The protective options for early humans were probably limited to using a natural shelter or constructing a makeshift one. Fire users could have moved their fire to a tree, a cave, a rock overhang, a hollow log, or a hollow in a rock or tree when rain threatened. Alternatively they could have used broad leaves, skins, bark, bushes or even bodies to construct a makeshift shelter. None of these options would be failsafe, and all would require attention for the duration of the threat. Fire using groups who kept fires in the open were either able to protect them, or they relied on other groups to provide them with an ignition source.¹⁵

Caves were a simple way to protect a fire and many Middle Pleistocene humans kept fires in caves. However, caves were not available to everyone and not always close to important resources. Fire sites in the open are usually close to water, food, fuel and lithic sources (Gowlett 2006: 306). To enjoy the ‘fire insurance’, and other benefits caves provide, fire using groups had to travel further to access important resources than those camped right next to them. Cave use involved overcoming the associated increased travel costs (Ofek 2001:165). Eventually cave users must relocate and, for a time at least, must live in the open.

5.5.3 Transporting Fire

Whenever a group accessed fire, or relocated, they had to transport fire unless they knew fire would be available at the new location. Middle Pleistocene human groups may have relocated because the patch they were in was depleted of resources, to take advantage of a seasonally available resource, or to follow a resource as it moved around. In the first case they may have just been looking for a better site, in the second they may have

¹⁵ A permanent well constructed hut or ‘tent’ would have sufficed to protect a fire. However, evidence for such structures during the Middle Pleistocene is rare and mostly equivocal (Nobel & Davidson 1996: 207). However, the evidence from Bilzingsleben is suggestive of fires kept in huts (Mania & Mania 2005: 101).
known where they were going and in the third the movement of game would have dictated transport distances. In each case individuals would have had to travel beyond their usual daily range, assuming they were not constantly on the move. The main constraint on moving fire is distance. Moving fire a short distance is not difficult. However, moving fire becomes increasingly difficult as the distance it has to be transported increases. The problem is that the simplest means of moving fire, carrying a burning stick or log, would have been potentially risky.

One constraint on moving fire is the tendency of a smouldering stick or log to go out if it is left unattended, or not continually oxygenated. Moving a fire a short distance of one or two km is not a problem. However, once the main fire was abandoned, smouldering sticks or logs would have needed regular attention. Those carrying the fire must keep it moving and watch to make sure it is still burning. Smouldering logs or sticks will continue to burn if those carrying them keep moving, because the log remains well oxygenated (Wrangham 2009: 193). While logs would not have burned indefinitely they may have allowed Middle Pleistocene humans to move around with relatively freedom. Success depended on keeping the burning stick or log moving, and establishing a fire as soon as the individuals carrying the fire stopped.

Middle Pleistocene fire users would not have travelled too far before establishing a new fire to cook or for the night. So if their sticks or logs went out before they started a new fire they could have gone back to the old one, which might still be smouldering. However, this would have wasted much energy at a time when resources could have been low, and also risky if it delayed the move too long.

Preparation is another constraint on moving fire. Early humans needed to make sure they had some dry kindling ready when the sticks or logs were going out. Kindling could have been quickly gathered in dry environments, but in others it may have needed to be gathered in advance and carried. Travellers may also have had to gather enough fuel for the night as they travelled to a new location. If they had been in the same area for some time
then fuel could be scarce during the initial stages of the move. To avoid losing fire early humans may have needed to ensure kindling and fuel arrived with the burning sticks or before them. It would be ineffective venturing forth with a burning stick only to discover that you could not sustain a fire when you needed to. If Middle Pleistocene humans knew in advance where they were going, and that fuel would be available on arrival, they need not have carried fuel.

I will assume Middle Pleistocene humans did not use complex methods to move fire around, such as fire totes or wicks. I will consider ‘fire carriers’, simple utensils for carrying fire, in Chapter Six as an alternative to burning sticks or smouldering logs. Simple fire carriers, although somewhat more cognitively demanding than fire sticks, would have increased the capacity of fire users to move fire over distance, and decreased the chance of the fire going out.

5.6 Taking Advantage of Fire

Accessing, maintaining and transporting fire is not cost free. The energy cost associated with any behaviour must be compensated. Whatever costs Middle Pleistocene humans incurred using fire; the fire had to provide an equal or greater return. Because many of the relevant variables are unknown it is difficult to estimate or quantify the cost of keeping a fire to prehistoric humans. The cost would also have fluctuated depending on the environmental context, and the strategies early humans implemented. However, we can safely assume that even when fire keeping costs were high, fire use would have have paid off.

There are many ways humans could have benefited from the energy fire provides (Rolland 2004: 254-255, Clark & Harris 1985: 19). We know

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16 \text{ I am assuming the day to day cost of keeping a fire was directly or indirectly paid for by the benefits the fire provided. If early humans had lots of spare time and energy derived from other behaviours, they could have kept fires that had minimal returns in relation to the cost of keeping the fire. However this is unlikely as costly behaviours that do not provide any benefit will not be selected, and we have no reason to think early humans had lots of spare time and energy. Presumably, the energy fire provided offset the cost of keeping fire.}
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that the Neanderthals and *Homo sapiens* of the Late Pleistocene used fire innovatively (Marie-Agnes et al. 2010, Wadley et al. 2009, Brown et al. 2009, Koller et al. 2001), and we suspect that fire, once controlled, would have been multifunctional. Predator deterrence, thermoregulation, lighting and cooking are the commonly cited advantages of having a fire. However, I suggest that cooking most likely provided fire users in all contexts with the energy required to offset the cost of keeping a fire, and provided the motivation to maintain fire on a daily basis.

Deterring predators would have been an important concern for early humans (Hart & Sussman 2009 *passim*), particularly during the transition from tree to ground sleeping (Coolidge & Wynn 2006: 5). Early humans were also adapting to hunting and scavenging behaviours that would have brought them into direct competition with top level predators (Stiner 2002). If having a fire decreased the risk of predation, then it would have been adaptive. Over the generations, more fire using humans would survive than those not using fire. However, this does not provide the individuals incurring the cost of keeping a fire going with any extra energy. Fire use probably had to provide some short-term gain for long-term gains to accrue. In my opinion, only large fires, and active interventions using fire, would deter large predators. Large, hot fires with logs burning overnight were probably required to effectively deter predators (Luibin 1992: 212-214), and these are costly to maintain. Fires also help you to see a predator approaching if the fire is large enough.

Having light at night reduces time constraints, if it allows you to do something that you would otherwise have to do during the day and to offset time spent gathering fuel during the day. However, not all fire users were always constrained by time. At times, when resources were scarce, or during temperate winters, the fire’s light could have transferred into cost reductions by providing more time, but for the most part, the energy value of night-light would have been minimal.

The warmth of a fire directly reduces the metabolic cost of thermoregulation. Humans today respond to cold by shivering (Gilligan 2007:
and eating more food. We also put on clothes, have heating and use shelters. Late Pleistocene humans wore garments, as many Middle Pleistocene humans must have (Gilligan 2007: 106, 109), but we do not know how effective these clothes would have been. A fire reduces the need for shivering and extra food, so the body uses less of its own energy reserves trying to keep warm. In many environments that Middle Pleistocene humans lived, the warmth of a fire and cooking would have been an important, even necessary, means of conserving energy and avoiding hypothermia.

However, many early humans lived in climates that were permanently or seasonally warm, where even night temperatures would not have fallen below zero. Certainly, a warm fire on a cool night would have been comforting, and may have provided some motivation to maintain a fire. However, in many contexts that fire users lived, a fire’s warmth could not have paid the cost of keeping a fire going continually, because there was no need to keep warm.

Gowlett points out that in conditions of extreme cold, fire is different from other technologies in that “it gives the highest return in circumstances of highest risk: if it should fail the results are disastrous” (2006: 306). A major investment in fuel procurement during optimal conditions, when risks and costs were low, has a big payoff at times when the cost of gathering fuel is high and the risk of losing fire critical (Gowlett 2006: 306). Similarly, when food and fuel are abundant the cost of procurement is low and the risk of losing fire reduced. However, when food is scarce the extra energy returns from cooking become critical, and the cost of gathering fuel increases as individuals spend more time foraging. A major investment in fuel procurement in times of plenty has a major payoff in times of scarcity.

The big payoff for keeping a fire was very probably cooking because it increases the nutritional value of most foods by allowing early humans to extract more energy from foods (Wrangham 2009 passim). Cooked food is easier to chew and digest than raw food, so you use less energy processing cooked foods. Cooking also allows you to eat more kinds of foods, increasing
diet breadth, thereby reducing the energy costs of foraging. The advantages of eating cooked food are immediate and ubiquitous. No matter where humans lived, individuals regularly eating cooked food would have increased their energy intake relative to those eating raw food (Wrangham 2009 *passim*). Wrangham suggests this increase may have been as much as 50% or more.\(^{17}\) Cooking, unlike the other benefits of fire, could have provided regular motivation and compensated for the cost of keeping a fire in all contexts fire users lived.

Cooking makes most foods tastier and taste is related to preference. Cooked foods may have been preferred over raw foods simply on the basis of taste, which provides motivation to cook food whenever possible. Experimental evidence suggests apes prefer cooked as opposed to raw foods (Wobber et al. 2008: 346), although they rarely eat cooked food in natural contexts. Cooking would have provided the motivation to have fire because cooked foods would probably have been preferred over raw foods. Evidence suggests cooked food provides a greater net energy return than do raw foods (Carmody & Wrangham 2009: 388). Thus, cooking also provides an immediate return in terms of energy. Cooking is perhaps the only behaviour that could have ubiquitously provided the consistent motivation and return for effort required for controlled fire use to evolve.

Cooking most probably was the primary means by which fire users met the cost of keeping a fire. This is not to say that the other benefits of fire were not important and even critical at times. As humans came to use fire in more adaptive ways the inclusive fitness of individuals in fire using groups would have increased. However, perhaps only cooking could have provided the regular return for effort and consistent motivation needed for fire use to become a viable behaviour in the initial transition from passive to active fire use. The other benefits of fire tend to be passively accrued simply by keeping the fire going and positioning yourself near it at the right time. As such, behaviour sufficient to keep a fire going would also provide light, warmth and

Cooking, however, requires active interventions beyond keeping the fire going to gain the benefit, such as delaying consumption, cooking methods and social considerations.

Cooking has behavioural, social and cognitive implications beyond those required to secure the other benefits of fire. Cooks must bring food to the fire or bring fire to the food once food is procured. This involves delaying consumption from when the food is acquired until it is cooked. The food also has to be cooked, which implies a method for cooking the food. While cooking may not have been overly complicated it was not simply a matter of throwing food items onto the fire. Some technique had to be used and care taken when cooking lest food or cooks get burned. Cooking would have involved tolerance and trust between group members. Individuals had to allow others to cook, and for the most part not steal food from others.

### 5.7 Summary and Discussion

Early humans, who depended on fire to survive, but could not make it, had to access, maintain and transport fire. They also benefited from fire in a way that compensated them for the cost of keeping fire and motivated them to engage in fire related tasks. Given the variety of contexts early fire users lived in we can infer they must have overcome a range of constraints. We know that some Middle Pleistocene, and perhaps even Early Pleistocene, humans overcame these constraints because by the end of the Middle Pleistocene fire use was a common human adaptation that was probably necessary for survival. Fire users either out competed fireless humans, or fireless populations became fire users under threat of extinction.

Most fire users could not have accessed fire from natural sources when their fire went out, so they had to rely on domestic sources. This meant interacting with other willing, or unwilling, groups to access fire. The main constraint on unwilling interactions was the increased costs and risks involved. The main constraint on willing interactions was that free access

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18 Predators may have had to be actively deterred by waving burning sticks at them, but we do not know if this occurred.
might not have been an evolutionary stable strategy. Middle Pleistocene humans had to use access strategies that overcame either, or both, of these constraints. Another key constraint was the distance between groups. Walking for many days to find fire would have been costly. Some groups probably would not have been able to access fire from other groups with any regularity because of the difficulties and costs involved.

Middle Pleistocene humans kept fires that would have required large amounts of fuel relative to the amount of usable energy the fire produced (Ofek 2001: 157-158). Fire users faced two main constraints procuring enough fuel to keep their fires burning. First, technological, ecological, and physiological constraints meant that they did not have regular access to high quality fuel. Second, logistical constraints meant that available fuel became increasingly more distant and difficult to access the longer a fire remained in the same location.

Middle Pleistocene humans may have tried to prevent their fires from going out. Protecting a fire in the open from rain would have been difficult without well constructed huts or shelters. The evidence for such structures prior to the Late Pleistocene is rare and mostly equivocal. Without huts, considerable ingenuity and cooperation would have been needed to protect open fires from rain. If fire users could not sustain an open fire during persistent rain then they would have relied on other groups who could, or people living in caves, to access fire whenever theirs went out.

Fire users probably had to move fire from one place to another. Moving fire a short distance would not have been difficult. The main constraint on moving fire any considerable distance is the instability of burning sticks and smouldering logs. This means any long distance relocations, or following game, required either strategic incremental movements, or some means to carry fire over long distances.

Middle Pleistocene humans did not live in environments where resources were always abundant and easy to access, so they probably did not
have a lot of spare time, or surplus energy budgets. This means the cost of keeping a fire was probably offset by energy the fire provided. Cooking is the most likely way fire could have consistently contributed to the energy budget of early humans. Therefore, cooking was probably the primary means in which they benefited from fire. Cooking would also have provided regular motivation to keep the fire going as cooked foods are likely to have been preferred over raw foods.

The importance of access or maintenance was relative to how good fire users were at maintaining their fires and how easily they could access fire, respectively. If fire was easy to access continual maintenance was not necessary and if fires never went out, access was not necessary. It is reasonable to think losing fire was not common. Middle Pleistocene humans who regularly lost fire through fuel shortages, unpredictable contingencies or their own neglect would have found survival more difficult than those that did not. Even if access to fire were relatively easy, regular fire loss would have meant regular periods spent without fire and its benefits. Frequent travel to access fire would have been costly unless groups lived very close to each other. Some fire using groups were probably isolated from others for long durations, given that populations were relatively small and widely distributed. For these humans, maintenance would have been critical while they were isolated. If other groups were not close by, the cost of access may have been significant. Again, being able to avoid losing fire would have put individuals at an advantage over those who lost fire regularly.

If some individuals were better at keeping fire than others, and keeping fire improved the inclusive fitness of group members, then fire loss could have been selected against. Those in groups who always lost fire would be out competed by individuals in groups that managed to keep their fires burning. This is important because for fire use to evolve, individuals had to be able to sustain fire over long durations, minimize costs, ensure relatively cheap access, or invent ignition technologies. And they had to evolve mechanisms that allowed them to do this in a group context, which involves constraining free riders.
However, this does not mean that fires would not have gone out, and if no one could access fire from others, fire use would have been restricted to fire prone regions. Thus, it is still reasonable to infer that accessing fire from other groups was important for widespread fire use to have evolved. For some fire users it may not have been as important as humans became more adept at maintenance. However, until fire making became common, I suggest accessing fire would always have been required, even if only infrequently. The alternative to the scenario I have proposed is that fire users have always been able to make fire. While the logistical demands of controlled fire use may be reduced in this scenario, this does not imply a reduction in social and cognitive complexity. Although this may have been the case, the evidence and common sense suggest it is less likely than the three-stage model for the development of fire use described in section 2.2 above.

In conclusion, I have identified some of the practical problems fire users would have needed to solve. These are tabled below. In retrospect, we know early humans did solve them because by the beginning of the Late Pleistocene controlled fire use was a common human activity on which the Neanderthals, *Homo sapiens* and late *Homo erectus* probably depended for survival. However, we do not know how they may have gone about this. What strategies could they have used and what strategies would have worked? The following chapter investigates these questions with the aim of establishing the least cognitively demanding activities that would have sufficed to be a competent fire user.
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<th>Practical Constraint on Successfully Engaging in the Task</th>
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<td></td>
<td>- Cannot rely on natural fires</td>
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<td></td>
<td>- Other fire users not proximate</td>
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<td>- Other fire users unwilling to give fire</td>
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<td></td>
<td>- Free access open to exploitation by free riders</td>
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<td><strong>Protect Fire</strong></td>
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<td>- Delayed consumption</td>
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*Table 4 Practical Problems Associated with Middle Pleistocene Fire Use*
Chapter Six: Solving Fire Related Problems

6.1 Introduction

This chapter investigates how Middle Pleistocene fire users may have gone about accessing, maintaining and using fire. My aim is to establish the simplest behaviours that would have allowed Middle Pleistocene humans to solve fire related problems, given the kind of constraints they had to overcome. It is important to note that the viability of a particular behaviour is relative to its context. Strategies that would have worked in some contexts, may not have worked in others. I begin by discussing how Middle Pleistocene humans may have gone about solving fire related problems. I then compare different possible options in terms of their relative efficiency and effectiveness.

My reasoning is that, although we cannot know exactly how fire users managed to solve a particular fire related problem, we can assume they must have behaved in the least cognitively demanding way that would have sufficed. If we can say that a particular behaviour would have sufficed and that it was less cognitively demanding than possible alternatives, then that behaviour can stand as grounds for making inferences about cognition. This depends on the assumption that increased behavioural complexity is a measure of increased cognitive complexity. I will argue that in general, optimal solutions to fire related problems are more cognitively demanding, and assume that fire users had to employ the least cognitively demanding solution that would have succeeded in a given context.

I will describe and evaluate how Middle Pleistocene humans might have solved each of the fire related problems describe in Chapter 5. Although it is difficult to quantify the costs and benefits of a given strategy, we can make relative assessments that one strategy was more likely to succeed in a given context or was more efficient than another. I am not suggesting that Middle Pleistocene humans were restricted to only one behavioural option. Being able to switch strategies may have been an important condition for fire use to evolve. My aim is to establish fire related behaviours that can serve as a basis for making inferences about cognition.
6.2 Accessing Fire

Accessing fire involved initiating a response, negotiating, or negotiating with, other humans, and transporting the fire to a suitable location. This section investigates four options available to Middle Pleistocene humans: access by stealth or force, or through free access or exchange. I am assuming that fire users who lost fire were strongly motivated to reacquire it.

Early humans may have done nothing when their fire went out, other than adjust to life without fire. When individuals in the group detected the presence of fire, they or everyone in the group moved toward the fire source with the intention of accessing it. In this scenario initiating the behaviour was dependent on some direct indication that fire was available. Middle Pleistocene humans probably did not usually travel beyond five to ten km to procure resources, and groups could well have been isolated from others for long durations. Therefore, it is reasonable to think some early humans had no option but to wait, or initiate a naïve search.

If a needy group were isolated from others they may have had to go without fire for long durations. This could have been critical if fire loss occurred during winter, or when food resources were scarce. However, Middle Pleistocene humans groups must have encountered each other at times, so eventually fire should have become available. Some may have lived in communities of relatively close local groups. Waiting for fire would have sufficed in most contexts, if groups in need eventually met up with a group who had fire, and if they did not have to wait too long. However, for some groups it may not have been effective. Groups who lost fire when isolated from others at critical times of the year may have struggled to survive. ‘Critical times’ were those in which temperatures regularly dropped below freezing point, or when food was scarce, because at these times more energy was required to keep warm or find food, yet individuals had less energy if nutritional intake was reduced. If Middle Pleistocene humans depended on cooked foods, then weeks spent without fire may have been critical.
The alternative was actively searching for fire before detecting any sign of it. Middle Pleistocene humans may have known or had some idea of where another group might have been, and this could have served as the basis for a search. If a fireless group knew where a group with fire was, they did not have to wait or search for fire. Searching for fire was not necessarily any more efficient or effective than waiting for fire, if a group was isolated from other fire users. Fire seekers may have travelled long distances only to find another group was not where they usually were. Fires can also be detected from a long way away, much further than we think early humans ranged in their day-to-day activities, thus helping to avoid naïve searches. In my opinion, Middle Pleistocene humans would not have searched blindly for fire, because it was potentially costly, and often not required.

While fire seeking would have sufficed, and may have potentially reduced the time between losing fire and regaining fire, it could also have been potentially more costly in some contexts. Overall fire seeking would only have been more effective and more efficient than waiting for fire if fire seekers had a good working knowledge of where other groups might be and how they moved about the landscape. If they searched or waited for fire, a group, or individuals from it, had to move towards a fire source before or when it was detected. Waiting or searching for fire is necessary, but not sufficient in itself to access fire from other humans. Once fire was detected, it had to be accessed from others by stealth or force, or through negotiation.

Accessing fire probably required group level collaboration directed at procuring a future reward. If not all group members were involved in the act of accessing the fire, those involved had to prearrange to meet up with those not involved at some future point in time and space. Any individuals that were not directly involved in the task presumably trusted others to return with fire or rendezvous with them later on. Accessing fire may have involved travelling beyond the group’s usual daily range. Individuals intent on accessing fire probably had to coordinate their behaviour with other group members by adopting complementary roles if they had to access fire by stealth or force.
6.2.1 Access by Stealth or Force

If a group with fire did not allow access to those without it, then those without may have tried to steal it undetected. This may have involved covert actions such as waiting in hiding for an opportunity, or overt actions, such as distracting members of the other group to provide individuals from your group with an opportunity to make off with a burning stick, or some hot coals. Such strategies would have been potentially time consuming and risky.

The alternative was forcing another group to give you fire, or forcefully taking over another group’s fire. Access by force would have involved direct action against all or some members of another group. Aggressive displays, or sheer weight of numbers, may have sufficed to gain access without physical violence, however in some contexts violence would have ensued if early humans adopted this option. A group without fire may have been desperate, and therefore willing to take risks they might not normally take. However, they were also likely to be physically weaker from eating raw foods and travelling, and not in a fit state to take on a strong well conditioned group.

Accessing fire through either stealth or force would have sufficed if group members were prepared to cooperate and well coordinated. The problem is fire defenders are likely to be just as committed, coordinated and able, perhaps more so, because they did not lose their fire in the first place. Either stealth or force implies risks, and potential reprisals, that could have been avoided. Given the way apes, including humans, tend to interact with individuals from other groups, these competitive scenarios cannot be ruled out. However, fire can be given without the giver losing fire. Thus, accessing fire could have been conducted on more amicable terms, without the loss of resources or life and limb.

6.2.2 Free Access and Exchange

Those with fire may have allowed those in need of a flame to access the fire unhindered. However, under some conditions unhindered access would have been costly if, for example, groups had to frequently travel long
distances as discussed in section 5.4.2 above. Frequent unidirectional access may not have been a viable option if donors were reproductively disadvantaged relative to borrowers (Ofek 2001: 160-161). If fire can be accessed for free it is not in anyone’s interest to invest the extra time and effort keeping a fire going continually (Ofek 2001: 160-161). If the benefit of having fire is equal to all members of a fire using group, but some individuals spend more time and energy maintaining the fire than others, and are not compensated, then fire providers are at a reproductive disadvantage. As such, free access in these circumstances was not a viable economic strategy. If individuals lack the cognitive capacity to figure this out, evolution will take over and no one ends up with fire (Ofek 2001: 160-161). Those who provide the fire needed to be compensated if everyone in the group did not share the workload.

However, this depends on the conditions that individuals kept private fires, fire was usually nearby and that gaining access was usually cost free (Ofek 2001: 160-161). This was probably not always the case for Middle Pleistocene humans living in small relatively isolated groups. If access was infrequent, because most groups could keep fire going for long durations and costly because groups had to travel long distances, then free access would have sufficed in most contexts. In this case, so long as groups without fire could find or encounter a group with fire, unhindered access would have been relatively cheap and effective compared to using stealth or force. The motivation for fire seekers to adopt this approach would have been to regain fire at low cost with less risk, whereas the motivation for the donors would have been to avoid conflict.

The most effective and efficient way to access fire, reduce risk and ensure neither providers, nor recipients, are disadvantaged would have been some form of exchange. In this scenario fire is a commodity that can be exchanged for other goods or services. Ofek suggests (2001: 161) that for fire use to evolve when people could not make fire, specialist fire keepers who traded in fire would have been needed.
6.2.3 Summary

The options described above involve individuals, or a group, moving towards another fire using group. Actively searching for fires, which could not be perceived, may have been more efficient than waiting until fire was detected, but not necessarily so. Fire seeking groups may have had to travel well beyond their daily range to access fire. The proximity of other fire using groups was an important constraint on accessing fire. Using stealth or force to access fire would have been potentially costly, with no guarantee of success. Options that avoided conflict and delays, and increased the chance of success would have been more effective and efficient. Allowing uninhibited access reduces the costs to both parties involved, and is arguably less behaviourally complex and cognitively demanding in terms of the intra group cooperation, planning and coordination associated with stealing or defending fire. However, this leaves competent fire keepers vulnerable to being out competed by free riders and the incompetent. Free access will work, but only under certain conditions. If access was not frequent, donors were not regularly exploited, and most groups within a region cooperated, free access would have been an efficient and effective way to access fire, and ensure all members of a fire using population could access fire when it was needed.

The problems associated with accessing fire could have facilitated the evolution of commodity exchange, and this would have been the most effective and efficient way to ensure access in all contexts. If competent fire users were being disadvantaged, some form of mercantile exchange probably had to evolve (Ofek 2001: 161). That is exchange based on the value of the commodities themselves. However, if free access was infrequent and not unidirectional it could have worked.

An intermediate economic solution between free access and mercantile exchange would have been some kind of reciprocal borrowing. However, we have no reason to think reciprocal borrowing would have been relevant in the context of accessing fire. First, borrowing would probably
have been one sided because it is unlikely neighbouring groups lost fire alternately, so free riding becomes a problem. Second, potential reciprocators probably moved around the environment, so it may not have been possible for those in need to recall a favour. They may have had to rely on a group they had not lent fire to, or worse, one they had recently borrowed from. Finally, keeping track of transactions, which may have occurred infrequently over the course of years, would have been cognitively demanding. The advantage of mercantile exchange over reciprocal borrowing is that transactions do not necessarily involve a time delay, or monitoring who owes what to whom.

6.3 Maintaining Fire

Maintaining a fire would have involved gathering fuel, tending the fire, keeping it from going out, and moving fire. This section considers how Middle Pleistocene fire users could have done these things. Middle Pleistocene humans may have gathered fuel as a group, or as individuals or subgroups. All group members may have stayed in the same vicinity, or they might have gathered fuel and other resources remotely from each other. When gathering fuel they may have only gathered enough to meet their immediate needs, or they may have stockpiled enough for a few days or weeks. Tending a fire would have involved adding fuel as required, or building the fire up at least once a day. Preventing a fire from going out would have involved building a shelter, moving the fire to a shelter, or cave use. Moving a fire involved carrying smouldering logs or hot coals. While these were not the only means available to Middle Pleistocene humans they meet two theoretical constraints, in that they are the simplest options that would have sufficed, and they are the least cognitively demanding.

6.3.1 Gathering Fuel

We do not know how Middle Pleistocene fire users went about gathering fuel. They may have tended to stay together as a group during the day, or individuals may have split up and gone about their own business. Stiner has argued (2002: 40) that Middle Pleistocene humans would have tended to stay together in groups, much like other large social carnivores. Kuhn & Stiner suggest (2006: 958-959) that the Neanderthals hunted in
groups, including women and children, without the strict divisions of labour we associate with modern foragers. Alternatively, Foley and Gamble suggest human evolution is marked by increasing levels of fission-fusion style foraging, with males gaining greater control over the distribution of resources (2009: 3268). These are very different scenarios. Given that archaeological evidence is ambivalent in differentiating between these two hypotheses, and both systems could have been in operation, I will need to consider both as possible models of Middle Pleistocene fuel gathering.

Middle Pleistocene humans may have tended to act in groups when hunting and scavenging, deterring predators or rival groups, sleeping, or simply moving about the environment. The protection group living affords primates from predators, and rival groups, requires that individuals tend to stay together (Dunbar 1996: 17). Of course many activities would have been conducted as individuals, or in pairs, such as tool making, grooming, mating and maybe child rearing. For now, I am assuming activities that would have directly benefited most members of the group were conducted as a group. In this scenario, a group gathered fuel as a group at some time, or times, during the day, before or after doing something else, such as going for a drink or foraging for food. They could have done this in response to a direct need, such as a need to cook or be warm, or because the fire needed tending, or they could have gathered fuel when the need was not immediate, such as in the morning before they foraged for food.

Gathering fuel in response to a direct need may not always have been possible, as I argue in Chapter Eight. The needs of individuals were unlikely to always coincide in time and space. This makes coordinating group behaviour according to immediate individual needs difficult. If Middle Pleistocene humans only gathered fuel when they needed to cook, then they had to delay consuming the food until fuel was gathered. Food may have needed to be guarded or carried while the group gathered fuel. Delaying consumption is a taxing cognitive task. For group fuel gathering to be effective, it is best removed from proximate needs so you do not have to gather fuel at an inopportune time such as at night or when you want to cook.
Early humans could have used expedient strategies in some contexts, depending on fuel loads and how often they relocated (Albert 2003: 477). However, gathering fuel at a more opportune time than when a need was urgent would have been more efficient, and more effective most of the time. Middle Pleistocene fire users could have gathered fuel when it best suited them, for example after cooking and eating a meal, at a set time such as in the morning, or opportunistically when they encountered fuel supplies. In this way Middle Pleistocene humans could have gathered fuel as a group when the need to gather fuel was not pressing.

The main advantage of this would have been that fuel gathering could have been organised in reference to some cue that was not directly related to the fire itself, or the current fuel supply. In this way provisioning could have been conducted routinely at an appropriate time of the day, or when it better suited the fire users. Another advantage is that all capable group members would have contributed to fuel gathering, thereby reducing the overall cost to individuals. It would also be easier to detect free riders who tried to avoid the cost of maintenance, and so those inclined to free ride would have found it harder to avoid gathering fuel. Easier monitoring of free riders would have been a key advantage of adopting this strategy.

Group gathering assumes that groups did not divide their labour. If food and fuel were not proximate, then individuals in the group potentially travelled much further than they needed to. Groups would also have needed to build up the fire whenever they left it unattended. So staying together was potentially more costly, and so less efficient and effective than possible alternatives in some contexts.

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19 Free riding is a problem for any public good from which all individuals in the group benefit, but to which all group members need not contribute (Dubreuil 2010: 53, Bird et al. 2008: 14769, Shinada & Yamagishi 2007: 330, Hawkes 1993: 347). Gamble et al. identify the need to monitor and deal with free riding as a primary evolutionary driver of human social cognition involving increased cognitive load, and increased demands on memory and theory of mind (2011: 118). The problem with gathering fuel separately is not who can gather fuel, but who wants to if they do not have to.
It is possible that some individuals gathered fuel while others did something else, such as forage for food. They could have done this while still in sight of each other, or remotely from each other. In this way groups could have gathered food and fuel at the same time. Although, this increases demands on social cognition, because individuals who spent their time gathering fuel needed to know that others would share food with them later on. Individuals could also have gathered fuel as it suited them rather than when it suited the group, thus reducing the problem of motivating group action, although this would have made free riders much harder to detect.

A problem with gathering fuel and food simultaneously would have been if these resources were not close to each other. In this situation the time and energy costs potentially increase if individuals did not split up to procure these different resources. If patches of food were not close to patches of fuel, say two to five kilometers apart, then dividing the groups labour would have allowed individuals to halve the travelling and carrying costs associated with procuring these resources. So long as half the group can gather enough food for everyone, while the other half can gather enough fuel for everyone, gathering resources that were not in the same vicinity synchronically was potentially far more efficient than the alternatives discussed above.

In open environments, if the distribution of resources was patchy, or when seasonal and contingent food shortages occurred, gathering resources remotely from each other may have been the only way, other than stockpiling, to ensure a consistent supply of fuel. As with foraging for fuel and food synchronically, there would have been an expectancy, or understanding, that individuals share resources. However, individuals also needed to represent, or know, what remote others were doing, and envisage future states of affairs, such as you giving me food later in the day. Being able to attend to, and represent, the action of remote others is a demanding cognitive ability.

I am not suggesting a culturally or ecologically prescribed division of labour, but rather a contingent one, given the fluctuating context of provisioning a fire. If fuel were abundant a few individuals could easily have
gathered enough fuel for all. If fuel were scarce then everyone in the group may need to help. Roles might not have been fixed and could have switched according to the contexts. One day I carry food and you carry fuel, the next day you carry food and I carry fuel, and the next day we both carry food and someone else carries fuel. What this scenario does imply is a degree of reciprocity towards, or compensation for, those who spent more time and energy gathering wood on any given day. Individuals are unlikely to have gathered fuel instead of food unless they knew they would receive a share of the food gathered by others.

Dividing the group’s labour in this way was arguably more efficient than gathering only food or fuel at one time in most contexts, and so potentially more effective. If half the group could gather enough food for everyone and the other half could gather enough fuel for everyone, then humans moving around as a group from a central place need not have made as many trips. If food and fuel were not proximate to the fire and each other, the group could split up and procure the necessary resources in half the time travelling half as far as those who stayed together.

By dividing their labour in this way individuals could tend the fire while others gathered food or fuel. This means the fire did not need to be built up when the group was off foraging, potentially saving on fuel and ensuring the fire did not go out. Some individuals may not always have engaged in foraging activities, such as the elderly or the injured. This may have been an important move towards the evolution of culturally prescribed divisions of labour that tend to mark off human societies from other social animals.

So far I have only considered the ‘short term’ needs of fire users: having the fire to cook with later in the day, or having enough fuel to last through the night. Even these needs suggest that fire users were not stuck in time and could consider their future needs, contra the dehumanising hypothesis (Tattersall 1998: 35, 2002: 153-155, Jordan 1999: 49, 221, 225, Lewis-Williams 92-92, 285). Fire users needed to ensure they had enough fuel to last the night and until they next gathered fuel on the following day.
This involved at least considering the current supply and proximate fuel loads in relation to tomorrow’s prospects. Tulving has suggested that crossing the diurnal divide would have required episodic memory and may have required a special evolutionary leap to produce brains that could think about yesterday and tomorrow (2005: 20). While fire use always involves having a ready supply of fuel available (Ronen 1998: 442-443), in some contexts contingency planning may have been needed and in all contexts it would have been adaptive.

Fire users may have stockpiled in anticipation of fuel shortages, difficult gathering conditions, less available gathering time and increased transport distances. They could have done this opportunistically, when they came upon abundant easy to access sources of fuel or at times when the conditions for gathering were favourable. A major investment in fuel gathering when conditions were favourable would have had a big payoff at times when fuel gathering was costly (Gowlett 2006: 306). By stockpiling, fire users could have avoided running out of fuel at times when fuel was difficult, or impossible, to gather, such as at night, during winter or storms, or when fuel loads were depleted. Stockpiling, being more efficient and effective than more immediate strategies, would have ensured the maximum returns from having fire. All fire users no matter where they were would have benefited from stockpiling. However, in many contexts, more immediate strategies would have sufficed.

We can imagine contexts in which stockpiling may have been necessary to keep a fire going. Long term occupations at the same site and cave use would have required stockpiling, because as local resources dwindled and travel distances increased, daily trips to a fuel supply would have become too costly. Evidence for long term occupations (Rivals 2009: 335-337, Karkanas et al 2007) and large fires at Middle Pleistocene sites (Gamble et al. 2011: 123) suggests stockpiling may have been required to keep up the fuel supply. Keeping a fire going during temperate winters may have required stockpiling because the cost of daily trips would have been expensive, and the risk of fire loss critical. This is the kind of situation in
which a major investment in fuel gathering during autumn would have had a major payoff in winter (Gowlett 2006: 306).

Fuel would have been more costly to gather during the wet season, and on hot afternoons in tropical, or summer, climates. When food was scarce and foraging was taking up most of the group’s time stockpiling might have been needed to offset the cost of daily fuel gathering. In contexts where food was scarce, temperatures were low, fuel was scarce and daylight hours were reduced stockpiling may have been the only way to conserve energy, reduce costs and ensure fire was not lost at critical times. Although it is difficult to say with surety that stockpiling was necessary in such and such a context, we can say with confidence that stockpiling would have been adaptive in most fire using contexts.

6.3.2 Protecting Fire

Strong wind could have been a problem for fires in the open. However, wind was not likely to put out a fire of optimal size. Strong wind might disperse a large fire, but you can always rekindle a new one from material that was still alight. The problem with wind is that it increases the rate at which an open fire burns fuel. On windy days early humans had to gather more fuel than on still ones, or they had to use some form of windbreak to reduce the rate of consumption. This could have made estimating fuel supplies difficult.

Domestic fires in the open will go out regularly if not protected from the elements. Heavy or persistent rain will put out fires in the open, unless people intervene, or the fire is unusually big. Middle Pleistocene humans trying to protect an open fire had two basic options, move fire to a sheltered spot, or build a makeshift shelter. Effectively protecting a fire from rain would have required a rapid response to any imminent threat. Any response, involving either sheltered relocation or shelter construction, had to be sustained for the duration of the threat. Without semi-permanent huts, or access to proximate rock shelters, or trees with thick canopies, it is hard to see how fire users could have protected a fire in heavy persistent rain. This is why
cave use may have been critical for controlled fire use to evolve, and persist, prior to fire making becoming a common activity (Ofek 2001: 162-167). If fire users in the open relied on fire users in caves to access fire, because those in the open were unable to protect fire, then long distance travel, inter group social negotiations and transporting fire become more critical.

6.3.3 Transporting Fire

There are many ways to move fire around, when fire making is impractical or impossible, and you do not have matches or a lighter, such as ‘fire totes’ and ‘fire cords’. Today, these techniques are restricted to particular survival and ethnographic contexts, and reality TV shows. The techniques, materials, and methods involved in these behaviours presuppose modern human cognition, so I will assume early humans did not use them. This leaves two basic strategies available to them, burning sticks or rudimentary fire carriers.

Burning sticks are unstable as discussed in Chapter Five. As such they may not have allowed early humans to travel far before having to start a fire. If fire users were in no hurry to get from one location to another, then they could have moved incrementally to a better patch or a seasonally preferred location. However, if they needed to move the fire a long way in quick time, then burning sticks or logs may have been a risky option.

The other alternative was some kind of fire carrier that required little or no modification. Shells or skulls of sufficient size would have worked, or pieces of timber, or bark, could have sufficed. Hot embers could have been scooped into the fire carrier and fed, if needed, as the group travelled. Early humans probably could have travelled further much faster with less risk of fire loss by using fire carriers than they could with burning sticks or logs. This would have been important if, for whatever reason, individuals needed to move fire a long way quickly. For example, if food or fuel resources ran out suddenly, if following game or if trying to steal fire undetected.
Individuals had to attend to the fire they were transporting, lest it go out unexpectedly. Burning logs had to be kept moving, and fire carriers would have needed attention and tending on long trips. Individuals moving fire may have needed support on long trips. For example, they may have required food, water, a rest or dry kindling. Individuals also had to decide who would transport the fire whenever they moved, unless everyone carried fire each time they relocated. Individuals transporting fire incur extra costs for the good of all group members. Those not involved would have relied on others to succeed, and probably entrusted them to do so. Given these implications for attention and social cognition, transporting fire was not always simply a matter of someone picking up a burning log each time the group relocated.

6.4 Using fire

Middle Pleistocene humans may have used fire to deter predators or for nightlight, and those in cold climates would have used fire to keep warm. The key consideration for these uses is the cost of acquiring enough fuel for fire to be effective in these ways. For a fire to provide protection and light, it would have to be relatively large and flaming (Luibin 1992: 212-214). Similarly, for a fire to provide all members of a group with sufficient warmth during cold periods, it would need to be well provisioned. While a smouldering pile of ash will burn for a day or more, remaining sufficiently hot to restart a fire, it does not provide sufficient heat and light for these purposes.

A large fire, say 60-100 cm in diameter, burning continuously, and fed on dry deadwood, requires large amounts of fuel. It is difficult to estimate the minimum amount of fuel fire users needed each day. Schiegl et al. have estimated (1996: 778) that five kilograms of wood fuel per day would be sufficient to keep a fire alight from one day to the next. I suggest that early fire users would have required more than this.\textsuperscript{20} Middle Pleistocene humans

\textsuperscript{20} In a simple test my supervisor Dr ED Lewis and I managed to burn around 30 kg of mainly dry deadwood in six hours. We added fuel conservatively and 24 hours after we stopped adding fuel the fire was cold.
were using fire to regularly cook, deter predators or keep warm, and fuel quality was generally poor, then it is reasonable to think they were using relatively large amounts of fuel. There is evidence to suggest the Middle Pleistocene humans at Hayonim cave used large amounts of grass, leaves and wood as fuel (Albert et al. 2003: 474). Ethnographic data also suggests (Mallot et al. 2007: 2038) that five kilograms of fuel would not have sufficed to meet the daily needs of early fire users. Evidence from some Middle Pleistocene fire sites suggests large amounts of fuel were being used (Gamble et al. 2011: 123).

Cooking was arguably the primary behavioural adaptation associated with controlled fire use and involved a) transporting food to the fire or fire to the food, b) allowing individuals to cook, and c) a means of cooking. It is unlikely early humans were fortunate enough that food was always procured close to the fire. For the most part food would have been transported to the fire or fire to the food. The latter would have been more costly and time consuming, as procured food may have had to be guarded and cooking fires established.

Cooking involves tolerance and trust. If dominant individuals took food from others, these individuals might not return to the fire with food or help maintain the fire. Cooking implies that stronger individuals did not take food from weaker ones, “No one will take food to a central cooking place if it is likely to be taken from them” (Sterelny 2003: 111). Bullies might have struggled to maintain a fire without the help of others. It follows that bullies should not steal food from individuals that help them keep the fire going. Individuals who have food taken from them need to find more food, thus are unlikely to have the time and energy to gather fuel. The problem is that food stealing disrupts the social cohesion and coordination required to provide for and use the fire. The cognitive and social consequences of this are discussed in Chapters Eight and Nine.

Given that early humans cooked different foods, different cooking methods may have been required. Cooking techniques, cooking implements
and cooking fires may all have been needed. In many cases, cooking is not simply a matter of throwing food into, or onto, an optimal size fire. Middle Pleistocene humans could have just thrown procured food items onto a communal fire when they returned to base. However, this is not likely because small items could have been burned, lost or difficult to retrieve, and large items indiscriminately placed on the fire may have put the fire out. A degree of care also needed to be taken when placing food items around, or in, the fire, and when retrieving them, to avoid injury from burns. If a few people wanted to cook at the same time, then taking turns and monitoring ones own food as it cooked may have been required.

Middle Pleistocene humans could have skewered food onto a stick and placed it over or in the fire. We have evidence of a deliberately fashioned 400 kya wooden tool from Schöningen 13 that may have been used for this purpose (Thieme 2005: 125-127, see Appendix Three). If the right materials are proximate, then you do not need to fashion cooking skewers in advance, but you do have to fashion them. If you do not have skewers at the ready, and you want to cook your food with skewers, then the time between procuring food and consuming it is increased. At Schöningen 13 the possible cooking implement, or the wood that it was fashioned from, was introduced from a remote place (Thieme 2005: 125-127).

Alternatively, they could have cooked on a separate ‘cooking hearth’ of hot coals and embers. You can have several of these, so you would not have to take turns. However, you do not want to be dragging coals out from the main fire unless it is a relatively big one. If you do need to scoop out coals, then you need a means of doing so. If you do not have cooking hearths ready, and you want to cook this way, then the delay between procuring food and consuming it is increased.

Cooking involves transporting and piling food, and a means of preparation. Not everyone who wants to cook can always cook at the same time. Cooking demands permissiveness. Stealing food is socially destabilising in the context of central placed foraging involving delayed consumption.
Cooking needs to be coordinated with other activities. Individuals probably preferred not to gather fuel when they had food to cook and were hungry, or after they had just consumed a large meal. Cooking involved delayed consumption and inhibiting desires to take food from others in the group. Evidence for cooperative meat sharing and cooking from Qesem Cave suggest these fire users managed to coordinate fuel gathering, cooking and consumption behaviours effectively (Stiner et al. 2009: 13207)

6.5 Summary and Discussion

I will now summarize the behavioural options described above. These were not the only means available. However, they were arguably the least cognitively demanding means required to successfully engage in fire related tasks, and maintain a sufficient degree of efficiency. I have identified contingent difficulties related to the environmental, ecological and social contexts associated with using fire, and the potential costs involved. From these I have proposed that some options would have been more efficient and effective relative to particular contexts, and in absolute terms.

Accessing fire involved approaching a potential fire source before or when one became available. If humans knew where other fire users were, they could have responded prior to any sign that fire was available. Otherwise they had to wait until one became available. Responding to a potential fire source may have involved travelling long distances well beyond the daily foraging range of the group.

Accessing fire probably involved hostile, or amicable, interactions with other groups. Hostile interactions were potentially more costly than agreeable ones. Free access would have been more efficient and effective than hostile encounters, if it did not happen regularly and was costly for borrowers. If free riders were taking advantage of willing donors, an incipient form of mercantile exchange may have been needed. Some form of mutually beneficial exchange may have been required to avoid the risks associated with hostile interactions, or the problem of free riding associated with free access.
Fuel gathering may have been conducted as a group with everyone focusing on one resource at a time, or gathering different resources at the same time. Alternatively, groups could have split up to gather different resources. Dividing the groups labour was potentially more efficient than acting as a group on one task at a time. Splitting up the group would probably have been more efficient than activities conducted proximately in some contexts. Stockpiling would have been the most efficient and effective means to solve the problems associated with gathering enough fuel in most contexts. In some contexts, it may have been the only way to ensure the fuel supply.

Caves and rock shelters will protect a fire from rain. However, caves increase the travel costs associated with gathering resources and travelling to and from a water source (Ofek 2001: 165-166). The evidence for cave use by early humans during the Middle Pleistocene (Rolland 2004: 257) suggests they did overcome this problem. Cave users were more likely to require an efficient means of accessing resources involving divisions of labour, stockpiling or exchange, given the increased energy costs involved. All these potential solutions would have been cognitively demanding.

For fire users in the open an alternative was to try and intervene when rain threatened to put the fire out. The effectiveness and efficiency of the simplest available options is relative to prevailing conditions. For example, being close to natural shelters or the materials to construct a shelter makes this task easier. Given the open environments many early humans lived in, protecting a fire from rain would have been difficult unless some kind of shelter was ready in advance. If early humans did not build huts or simple shelters, then they may have had to access fire from humans who lived in caves.

Transporting a fire may have involved using burning logs or fire carriers. Individuals transporting the fire probably required support from other members of the group. If groups were not in any hurry to get from one place to another, burning logs would suffice. Fire carriers would have been a more efficient and effective way to move fire long distances. A social
problem associated with transporting fire would have been who moved the fire when a group relocated? The individuals transporting fire could incur considerable cost for the good of all, and those not transporting the fire relied on them to succeed. This implies trust and mutual understanding of different roles and their significance to the group’s future interests.

Middle Pleistocene humans may have used fire for light and protection, and some used it for warmth. They probably mostly used poor quality fuel and kept fires burning continually. These uses and conditions imply that relatively large amounts of fuel were being consumed daily. Cooking most likely provided both the energy and the main motivation to engage in fire related tasks. This involved moving food or fire, a cooking method and allowing individuals to cook their food. Whereas other fire related tasks could have been realised in different ways, cooking would have required these behaviours. Food stealing in particular could have disrupted the social cohesion of a fire using group, which would have undermined the group’s capacity to solve fire related problems.

6.6 Conclusions

I have identified a range of strategies that early humans could have used to engage in fire related tasks, and solve the kind of problems fire users encountered. In some contexts particular strategies may not have worked. For example, expedient fuel gathering may have sufficed for short term, but not long term occupations (Albert et al. 2003: 477). If early humans were unable to solve one problem, say accessing fire, then they had to be able to solve another, such as indefinite fire maintenance. It is reasonable to think fire users at different times and places adopted the kind of behaviours I have outlined above.

Controlling fire was never simply a matter of accessing fire as needed, and feeding it fuel until it was not. It involved a suite of behaviours that had to be conducted in a variety of environmental, ecological and social contexts. These behaviours had different goals, which were directed towards realising an ultimate goal, which was often spatially and temporally remote from the
required activity. One activity does not necessarily follow procedurally from the other, as with tool making and foraging (Ronen 1998: 443). Tending a fire does not necessarily follow from gathering fuel, cooking does not necessarily follow from tending a fire and fuel gathering does not necessarily follow from cooking.

Each fire related behaviour has its own procedures that had to adjust to fluctuating ecological and social conditions. Unlike more mundane behaviours such as foraging or tool making, there was not always a predetermined sequence or frequency with which each activity occurred in relation to the other activities. For example, cooking and fuel gathering may have occurred daily, transporting fire weekly or monthly and accessing fire yearly. Each task involved different operations with different cognitive implications, for example, gathering fuel, cooking a meal, carrying a burning log, or interacting with individuals from other groups. This complex of temporally and spatially discreet actions related to a single domain of behaviour, and often directed toward a future or ultimate goal may be unprecedented in human evolution. These fire related tasks, possible problems associated with them and their cognitive implications are tabled below.
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<tr>
<td>-Proximate or remote</td>
<td>-Reciprocity</td>
<td>-Knowing what remote others were doing</td>
</tr>
<tr>
<td>Individual Gathering</td>
<td>-Acting remotely from each other</td>
<td>-Group contingency planning</td>
</tr>
<tr>
<td>-Stockpiling</td>
<td>-Fire Must be kept oxygenated</td>
<td>-Attention to the task</td>
</tr>
<tr>
<td>Transporting Fire</td>
<td>-Must decide who carries the fire</td>
<td>-Being ready in advance</td>
</tr>
<tr>
<td>-Burning logs</td>
<td>-Needs to be fed and attended to</td>
<td>-Division of labour</td>
</tr>
<tr>
<td>-Fire Carriers</td>
<td>-Increased travel costs</td>
<td>-Stockpiling</td>
</tr>
<tr>
<td>Protecting Fire</td>
<td>-Group level cooperation</td>
<td>-Division of labour required</td>
</tr>
<tr>
<td>-Cave use</td>
<td>-Novel problem solving situations.</td>
<td>-Novel action planning</td>
</tr>
<tr>
<td>-Sheltered Relocation</td>
<td>-Increased social coordination required to bring in fuel</td>
<td></td>
</tr>
<tr>
<td>-Shelter Construction</td>
<td>-Need a large fire to be effective.</td>
<td>-Monitoring and dealing with free riders</td>
</tr>
</tbody>
</table>

**Table 5 Cognitive Demands Associated With Fire Related Problems**
Chapter Seven: Defining and Inferring Human Cognition

7.1 Introduction

This chapter describes the cognitive abilities that I will argue we can conditionally infer from fire use, and discusses behavioural criteria we can use to identify these abilities. I will outline why cognitive abilities are hard to define, and offer a generally accepted definition of cognition. I then review some behavioural definitions used to identify and measure different aspects of cognition in humans and other animals. From this I propose criteria that are applicable to behaviours required to solve fire related problems. Given the literature on cognition is extensive I must be selective, focusing on the abilities and criteria of direct relevance to the context of early human fire use.

Because we cannot observe the cognition of prehistoric humans directly we must infer behaviours and behavioural patterns from evidence, and then infer cognition from these (Coolidge & Wynn 2009: 68-69, Osvath & Osvath 2008: 661, Schwartz 2005: 228). This involves identifying the minimum necessary cognitive competence required to engage in a particular behaviour (Coolidge & Wynn 2009: 177). I have identified fire related tasks that I will argue provide grounds for making inferences about cognition. My aim here is to describe the cognitive abilities that I will argue were probably required or would have been adaptive in solving fire related problems.

I begin by describing cognition in general and how human cognition today differs from that of other animals. I then define the aspects of human cognition that I suggest are relevant to fire use, focusing on executive functions and social cognition. Next I discuss features of human cognition, such as executive control, working memory capacity, episodic memory, detached representations, informational theory of mind, collective intentionality and intersubjective communication. These are associated with cognitively demanding behaviours, such as inhibiting responses, anticipatory planning, delaying gratification, future directed group level cooperation and providing a public good. These serve as a basis for establishing behavioural criteria applicable to fire related problems, from which we can infer the operation of human cognitive functions.
7.2 Cognition

Despite a general consensus as to the processes that come under the umbrella of cognition, there is no consensus as to the best way to define, model and identify these processes (Ardilo 2008: 94, Auenger & Curtis 2008: 318, Jurado & Rosselli 2007: 213, Scott-Phillips 2007: 387, Gershenson 2004: 151, Barkley 2001: 2, Botha 2000: 150, Kamil 1998: 4). There are several reasons for this. We do not fully understand how the brain gives rise to the neuropsychological mechanisms that govern cognition. There are also several different theories on the neural organization and discreetness of cognitive functions, and on how to model them (Fisher 2006: 291, Gershenson 2004 passim, Atkinson et al. 2000 passim).

The current situation is that no single approach seems to have a clear advantage over the others because some theoretical perspectives seem well suited in one cognitive context, but not others (Gershenson 2004: 135). Socially and historically derived biases also tend to cloud research into the mental differences between animals, early humans and us (Corby & Roebroeks 2001 passim, Stoczkowski 2002 passim, Corby 2003 passim). Despite these difficulties, we can define cognitive processes as those governing the acquisition, retention, representation, interpretation, organization, and use of information (Dukas 2004: 347).

7.3 Human Cognition

Contemporary human language, self-awareness, theory of mind and representational capacities are different from the cognitive abilities of other animals (Amati & Shallice 2006: 357-358). These abilities are either not evident at all in other animals or greatly enhanced in humans today. The degree, if any, to which the other great apes possess or can acquire these aspects of cognition is limited (Penn et al. 2008 passim). It is generally agreed that humans have evolved neuropsychological mechanisms and behaviours that enable uniquely human ways to acquire, retain, represent, integrate, interpret and transmit information (Coolidge & Wynn 2009, Tomasello 2009, Donald 2001, Deacon 1997, Mithen 1996). The cognition of people today is a product of complex culture and language, which seem to be distinctively
human phenomena (Tomasello & Rakoczy 2003: 121). Without languages, cultures and complex social institutions, the cognitive abilities of humans might not be all that different from that of the other great apes (Tomasello & Rakoczy 2003: 121). This is because different developmental contexts can give rise to very different cognitive phenotypes (Sterelny 2003: 163).

Humans communicate with each other linguistically. Some features of human languages that are not evident in the communication of the other great apes are ostensive signalling, predication, displacement, symbolic reference and syntax (Tomasello 2009 passim). Language trained apes can acquire these abilities, except complex syntax, to a limited degree (Deacon 1997: 84-101, 122-127). There is no unequivocal evidence for these facets of language in wild apes or primates (Tomasello 2009 passim, Deacon 1997 passim). I will argue that ostensive signalling, predication and displacement would have been required to control fire. For example, drawing attention to a fuel source, informing others of an intention to gather fuel and request help, or providing information about a free rider would have been adaptive.

We interpret the perceived world in terms of unobservable causes or mental states, and higher order role governed relations embedded in culturally acquired conceptual realities (Penn et al. 2008: 111, 127). For example, we might infer witchcraft from illness, we might infer religious beliefs from an individual’s behaviour or we might infer that individuals act in a certain way because they are a soldier, a doctor, a wife or a father. There is no evidence to suggest other animals use information in this way (Penn et al. 2008 passim).

Contemporary humans can reflect on information without any proximate perception or sensation referring us to the information being represented (Amati & Shallice 2007: 359-360, Sterelny 2003: 4). We can think of food when we are not hungry, food is not perceivable and no stimulus associated with food is present. Cognitive scientists refer to these as detached or decoupled representations because they are not associated with the situation currently being experienced (Gärdenfors 2008: 52, Sterelny 2003: 4). We can reflect on the past and imagine possible future situations.
from the perspective of a socially constructed, apperceptive and nameable self (Edelman 2005: 15, Tulving 2005 passim). There is no evidence to suggest that other animals can represent information in this way, whereas it is a fundamental aspect of human cognition.

Humans can suppress and regulate selfish, conditioned and prepotent responses to proximate rewards in favour of future rewards, or for the good of the group. Other primates do not seem to inhibit responses in this way (Stevens & Hauser 2004: 62). This may be because in primate societies other than human, inhibiting automatic or instinctive responses is not adaptive. I will argue that fire use established a context, different from foraging for food or tool use, in which being able to inhibit responses to secure future rewards and to maintain social cohesion would have been adaptive.

Today, human social cognition differs from that of other apes in two fundamental respects. We have an informational or representational theory of mind, which involves representing the mental states of others as different from one’s own. Individuals can know that others hold things to be true that are false. We can also understand triadic relationships, which involves two or more individuals sharing attention or communicating information about some third person or thing (Saxe 2006: 235). These basic features of human social cognition enable language and the high fidelity transmission of cultural concepts that have been fundamental to our success as a species. I will argue that they were also critical in solving fire related problems.

In summary, language (Deacon 1997 passim), causal reasoning (Penn et al. 2008 passim, Premark 2007 passim), social cognition (Frith 2008 passim), inhibitory control (Ardila 2008 passim, Barkley 2001 passim), and our ability to attend to and remember displaced information (Coolidge & Wynn 2009 passim) are unique, or greatly enhanced, in humans relative to other animals. These cognitive abilities enable cultural learning, future directed cooperation, planning, and allow individuals to act in the interest of the group, rather than themselves. Early humans would not have needed the complex features of human cognition and culture evident today to control
fire. However, while early humans would not have required the range of human cognitive abilities that we recognize today incorporating complex syntax, culturally constructed realities and metaphysical concepts, I suggest they would have needed some fundamental aspects of human cognition. Aspects of human cognition related to representing goals, executive control, social cognition and communication would probably have been needed for controlled fire use to evolve. The following sections describe these fundamental aspects of human cognition.

7.4 Executive Functions

The concept of a higher order system, or systems, coordinating more basic cognitive functions is well supported by various lines of evidence and generally accepted (Coolidge & Wynn 2009: 36, Baddeley 2003: 835, Donald 2001: 139, Barkley 2001: 3). The central executive, conceived of as either a unitary system or multiple integrated systems, is thought to govern, attention, inhibiting prepotent responses, decision-making, planning and switching from one task to another (Coolidge & Wynn 2009: 36, Aron and Poldrack 2005: 1285). The central executive can be contrasted with automatic or impulsive cognitive processes that generate quick and spontaneous responses derived from positive or negative associations in time and space between situations and behaviour (Hofmann et al. 2008: 963).

The executive system is thought to control, or to override, automated or impulsive processes (Hofmann et al. 2008: 963). It is required for cognitively demanding operations such as planning in novel situations, overcoming habits, and for generating explicit judgments and decisions. The central executive “takes control when novel tasks are introduced, when preexisting habits have to be overridden, or when danger threatens and task relevant decisions must be made” (Coolidge & Wynn 2009: 36-37).

The idea of impulsive or automatic processes and executive or controlled processes operating in conjunction or competition is generally accepted. Although, it is unlikely that any clear functional or neurological distinction exists between the two. Cognitive scientists often make a
distinction between conscious explicit memories and unconscious implicit memories. Although, evidence suggests these systems do not necessarily divide on consciousness (Reder et al. 2009: 43, Tulving 2005: 16). We learn complex cognitive skills through conscious, controlled and reflective effort that then become internalized and automated through practice, such as learning to drive, play the piano or knapping skills (Rossano 2003: 213-214, 2009: 29-30). Daily tasks are performed almost automatically; however, sometimes it is necessary to alter a routine, such as gathering fuel, if something in the environment changes, and the routine becomes ineffective (Okihide & Isoda 2010: 1, Barber & Carter 2005: 905).

Ardilo suggests (2008: 94) that the central executive comprises two different, but closely related executive functions. First, there are metacognitive executive functions that include problem solving, abstracting, planning, strategy development and implementation, and working memory. Second, there are emotional / motivational executive functions, such as the coordination of cognition and emotion, and inhibitory control (Ardilo 2008: 94). The critical inhibitory functions of executive control include acting in a way I do not want to act or refraining from acting in a way that I am compelled to, and maintaining focus on a task in spite of interference. The apparent physiological objective of inhibitory control “is the suppression of internal and external inputs that can interfere with whatever structure of behaviour, speech, or cognition is about to be undertaken or currently underway” (Ardilo 2008: 94 [Fuster 2002: 382]).

Executive functions also allow for increased cognitive flexibility. Cognitive flexibility is indicated by an ability to adapt behavioural strategies to unexpected changes in surroundings. This kind of flexibility is adaptive when environmental changes affect the efficiency and effectiveness of a problem solving strategy. In this sense, cognitive flexibility refers to a capacity to change behaviours or strategies as the situation demands.

Working memory capacity is considered a measure of attention, and of conscious control over action (Engle 2002: 19). Executive functions are
often described in reference to the concept of working memory, in particular the model proposed and developed by Baddeley (2003). In principle, most cognitive scientists agree on the need for a system of limited attentional capacity that is supported by peripheral memory storage systems. Baddeley’s model of working memory incorporates the phonological loop for storing auditory information, the visuospatial sketchpad for storing visual information, the episodic buffer for integrating memories and current information in conscious awareness, and the central executive that governs and integrates the information being attended to (see Baddeley 2003 for a full review). An important function of the central executive is conscious intervention when routine behaviours are not sufficient.

Executive subsystems are thought to be fluid processes, and draw on information from more crystallized memory systems (Baddeley 2003: 835). Working memory is an important component of general fluid intelligence, and represents a domain free limitation in the ability to control action (Engle 2002: 19). Coolidge and Wynn suggest that working memory would be more aptly referred to as “working attention” (2009: 36). For these reasons, working memory is associated with conscious awareness (Dijksterhuis & Aarts 2010: 484, Coolidge & Wynn 2009: 43, Engle 2002: 19-20).

7.4.1 Response Inhibition

Humans can inhibit responding to somatic or environmental stimuli, such as hunger or the presence of a preferred food, in ways that other animals cannot. We can temper, suppress and regulate behavioural responses that are inappropriate or no longer required, and initiate behaviours directed at future goals in fluctuating environments (Verbruggen & Logan 2008: 418). Of course, we act impulsively at times to our benefit, cost or embarrassment. In extreme cases, the personal and social costs of failing to inhibit responses can be devastating. Addictions, obsessive compulsions and much social pathology are associated with a diminished capacity to inhibit responses. Response inhibition is the hallmark of executive control or conscious self-regulation (Verbruggen & Logan 2008: 418).
Executive functions are not usually described in terms of behavioural criteria or in reference to the functions they serve in practical problem solving contexts (Ardilo 2008 93, Barkley 2001: 2-4). Visual spatial sketchpads and phonological loops do not have to compete for energy sources and mates (Barkley 2001: 2). Unfortunately, using information processing metaphors to describe executive functions does not incorporate ideas of a sense of the future, self-control or the more distal social dimensions associated with executive functions (Barkley 2001: 2). In response to this, Barkley defines the executive functions as behaviour directed towards oneself in self-regulation, with the function of modifying one’s behaviour so as to change the future outcomes for that individual (Barkley 2001: 5). He identifies four interrelated executive functions involving self-regulation through behavioural inhibition, two of which I will argue would have been critical to control fire.

I suggest that mentally representing ‘event-response-outcome’ sequences and simulating courses of action, and representing events or situations that motivated action would have been involved in fire use. For example, imagining the fire going out may have initiated an emotional aversion to this situation that motivated fuel gathering at a time when the fire was not going out. Following Barkley (2001: 5) we can describe executive functions operationally in terms of future directed self-regulation.

However, as we cannot directly observe the cognitive processes governing self-regulation we must identify behavioural manifestations relevant to the kind of adaptive problems self-regulation allowed humans to solve. Barkley identifies the following activities that may have required behavioural inhibition; reciprocity associated with the formation of social coalitions, tool use, imitation, mimetic skill and communication, and defense against the social manipulation of cheaters and free riders (2001: 15). Coolidge and Wynn identify the following behavioural manifestations of executive functions that I will argue would have been adaptive in fire using

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21 Barkley also identifies speech to the self and play to the self. While these may have been important for controlled fire use, early human fire users may not have needed a spoken language, or to construct novel scenarios from familiar situations by rearranging the parts.
contexts: spatially or temporally remote action, response inhibition, innovative action plans and group contingency planning (2007: 81). Three kinds of future oriented behaviours are thought to provide reliable indicators of future directed self-control involving an extended working memory capacity and episodic memories: anticipatory planning, delayed gratification and prospective memory (Atance and Jackson 2009: 380). I describe each of these behavioural manifestations of future directed self-regulation below.

7.4.2 Anticipatory Planning

Planning is defined in terms of anticipating the future and involves representing and preparing for a future goal. Planning is by definition a future oriented behaviour (Atance & Jackson 2009: 381). Examples of planning include, anticipating and preparing for future events, organizing the day’s activities, such as the routes to be taken when foraging, monitoring the behavior of other individuals for future reference, or group contingency planning, such as stockpiling. All these kinds of planning would have been adaptive in solving fire related problems.

Contemporary humans can plan ahead on the basis of past experiences and in anticipation of needs and motives we are not currently experiencing: “We plan for a meal even though we are not hungry; we stockpile firewood even though we are not cold…” (Paxton & Hampton 2009: 238). We can foresee that we will be hungry tomorrow, that it will be cold in winter or that a fire will go out and prepare in advance. This is called anticipatory planning (Gärdenfors 2004: 239-241). Some scholars argue that non-human apes, and other animals, are incapable of planning for a future need (Gärdenfors 2004: 240, Roberts 2002: 473, Deacon 1997: 414, although see Paxton & Hampton 2009, Osvath & Osvath 2008 and Noser & Byrne 2007 for an alternative view).

“The Bischof-Köhler hypothesis posits that nonhuman animals cannot plan for future motivational states that differ from a current state” (Paxton & Hampton 2009: 238). While some apes seem to anticipate needing a tool up to fourteen hours ahead, these results are inconclusive as the choice of tool
may be explained in other ways (Suddendorf & Corballis 2010: 292). There is ongoing debate into exactly what studies looking for anticipatory planning in animals have demonstrated (Suddendorf & Corballis 2010: 292). The fact that there is no clear evidence for planning in animals after several decades of study is in itself telling. As it stands, humans plan ahead, while there is no clear evidence that other animals do.

People today can remember their past and imagine their future. This is what cognitive scientists refer to as mental time travel: mentally projecting ourselves backward in time to re-live, or forward in time to pre-live events (Suddendorf & Corballis 2007: 299). This was a critical human cognitive adaptation that is probably associated with the evolution of higher-order consciousness (Morin 2006: 369, Edelman 2004: 98-104). Forethought can be defined as projecting the self forward in time to anticipate future states and needs and plan for them (Atrance & Jackson 2009: 380). Retrospection and forethought build on semantic memory and procedural memory and the facts they encode about the world. However, the semantic and procedural memory systems can function without subjective, temporal and apperceptive dimensions in humans and other animals (Suddendorf & Corballis 2007 passim). Episodic memories are thought to enable the important sense of ‘a self in time’ associated with mental time travel (Tulving 2005: 18).

Episodic memories involve more than knowing that something happened or is likely to happen in certain circumstances. They involve remembering what happened, when it happened and whom it happened to from the perspective of a self (Tulving 2005: 18). As such, episodic memories add an important autobiographical dimension to other memory systems enabling them to operate beyond proximate associative motivations and contexts (Tulving 2005: 13). Tulving suggests the function of episodic memory is to allow mental time travel (Tulving 2005: 14). Other animals certainly have efficient and capacious memories; the elephant is said to never forget and dogs remember people they have not sensed for many years. However, the memories of animals, unlike ours, only seem to be activated in response to some proximate stimuli, such as hunger or a threat.
Although non-human animals engage in future oriented behaviours, such as web building, migrating, nest building and food caching, they do not need forethought to do so, as these can be accounted for in terms of stimulus-response associations (Tulving 2005: 17-18). In these cases, natural selection has produced adaptive behaviours that take advantage of environmental regularities. These behaviours can be explained in terms of innate drives, conditioned reflexes, associatively learned routines, and proximate motivations cueing the retrieval of procedural and semantic memories. We have no reason to believe other animals use episodic memories to engage in future oriented behaviour (Stevens 2010: 5, Tulving 2005: 17-18). The hypothesis that animals cannot form episodic memories and so are ‘stuck in time’ is yet to be convincingly refuted (Roberts 2002, Suddendorf & Corballis 2008, but see Zental 2009, Clayton & Dickinson 1998, for a review of research into episodic-like memory in non-human animals see Behavioural Brain Research 2010, special issue on episodic memory, 215(2): 161-332).

The idea that non-human animals are stuck in time has been extended to early humans (Tattersall 2002: 155, Lewis-Williams 2002: 92-92, 285, Jordan 1999: 225). These scholars argue that only recent Homo sapiens associated with modern human behaviours could think beyond their immediate contexts. The extreme version of this hypothesis is that prehistoric humans including late Neanderthals and early Homo sapiens had no sense of time or self-conscious awareness. Shreeve neatly summarizes this view of early human cognition as follows; “…a Neandertal waking up…would set out with little plan in his head except eating, wherever and whenever Neandertal and Neandertal food happened to meet each other” (Shreeve 1995: 156). This idea makes little sense if Neanderthals cooked their food as we suspect they did, because they would need to take fire with them in anticipation, or take food back to the fire. Although this idea is increasingly at odds with the evidence (Zilhao et al. 2010, Rabinovich et al. 2008, Koller et al. 2001) it persists. A current study on the hunting abilities of Middle Pleistocene humans seeks to discover if “…the quality education needed to become an
expert hunter was possible without the transcendence of the here and now and a release from proximity by symbolic and syntactical language”.

The test for future thinking in animals, and presumably early humans, is demonstrating that they could provision for a need that they were not currently experiencing but would experience in the future (Raby & Clayton 2009: 317). We need to show “that animals at some point $T_1$ in their ‘spare time’, engage in a given behaviour $X$ which is not controlled (instigated and maintained) by any physiological stimulus, external or internal, but which can be shown to be of benefit to the animal at some future time $T_2$” (Tulving 2001: 1513).

If early humans exhibited intelligent and purposeful behaviour that meets this criterion it is reasonable to infer the behaviour was governed by forethought. Suddendorf and Busby suggest that “to ascribe foresight we need evidence that an individual mentally represented a temporally displaced scenario: that the individual based its actions on the consideration of a future benefit” (2005: 112). We need to rule out chance, and show that some direct somatic or environmental stimulus did not initiate and sustain an innate or learned response (Suddendorf & Busby 2005: 112).

My key concern is were stimulus-response associations sufficient to motivate individuals to enact fire related tasks, or were representations of a displaced goal or situation required? It is often difficult to identify motivational and cognitive influences when testing for future thinking in humans or animals. In healthy human adults there is no sharp operational divide between the proposed memory systems we use (Tulving 2005: 16). However, psychological and neurological evidence suggests some clear disassociations between different domains of memory (Coolidge & Wynn

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Testing for forethought in animals is also difficult because we lack access to verbal report.

Despite this, cognitive scientists generally focus on future oriented behaviours, where we can rule out innate or conditioned responses to proximate cues as motivating the behaviour, and where the time depth or response breadth between behaviour and its related outcome can be measured. Forethought can be defined as mentally representing future situations, and differentiating these from past or current situations. Acting in the present to bring about or avoid future consequences in the absence of proximate intrinsic or extrinsic stimuli may indicate forethought.

7.4.3 Delayed Gratification

Delayed gratification, or “future-oriented self control” (Atrance and Jackson 2009: 381), involves passing up an immediate reward in favor of a greater but more temporally remote reward. Tests for delayed gratification measure the capacity for response inhibition involving representing durations and future rewards. In classical tests for delayed gratification, children are presented with desired but unequal rewards and told they can have a smaller amount now or wait and have a larger one later. Although there is some variation in test results, the ability to delay gratification increases with age (Atrance and Jackson 2009: 381). In these tests, the children can see both rewards, so they need not represent or envisage the greater reward. The fact that younger children cannot wait to get a reward that they can see, when no siblings or other children are present to take the delayed reward, suggests that an inability to assess durations is responsible for their behaviour.

Similar tests derived to measure delayed gratification in apes and other animals suggest they do not, or cannot, delay gratification to the extent humans do (Suddendorf & Corballis 2010: 294-295, Stevens & Hauser 2004: 62). Evidence suggests the performance of chimpanzees and bonobos exceeds that of other animals and equals humans in some experimental contexts involving food rewards (Rosati et al. 2007: 1654-1656). Either other animals cannot appreciate the temporal constraint at all and simply go for what they
can get, or they understand they can have a greater reward later but cannot pass up an available opportunity. Given that the future is uncertain for most species it is not unusual that animals discount future rewards in favour of more immediate ones (Stevens & Hauser 2004: 62).

Monkeys, like other animals, cannot delay gratification for more than a few seconds (Suddendorf & Corballis 2010: 294). However, non-human apes may be able to wait for a few minutes, although performance varies greatly from one individual to another. In one study, some chimpanzees delayed gratification for up to eight minutes to receive a reward that was forty times greater (Suddendorf & Corballis 2010: 294). While this result is significant, it must be noted that humans can delay gratification for hours, days, weeks, months and years. To decline an immediate reward in favour of a future one is a cognitively taxing planning situation, involving not only rejection of the proximate reward, but tolerance against the discomfort of rejection (Osvath & Osvath 2008: 663).

Delayed gratification in the context of fire use was arguably more demanding than tests conducted with human children and other primates. This is because the goal motivating fire related behaviours, a need to cook or tend the fire, may not have been apparent if individuals had to choose between these and a more proximate reward. In these situations future rewards had to be imagined, unlike tests in which subjects can see both rewards. The delay was also potentially longer in fire related activities than in the tasks designed to measure delayed gratification in human children and other animals. These measure delays of minutes, where as fire related tasks may have involved delayed gratification directed at goals many hours or days in the future.

7.4.4 Prospective Memory

Prospective memory can be defined as remembering to do something at some future point in time (Coolidge & Wynn 2009: 271). It involves distinct processes such as, developing a plan, remembering the plan and remembering at some future point to enact the plan (Kliegel et al. 2000: 1042, Atance & O’Neill 2001: 533). A key concern for researchers into prospective
memory is what cues or triggers the retrieval of a previously formed plan or intention (Graf & Grondin 2006: 8). To this end prospective memory tasks can be considered event based or time based. In event based prospective memory tasks, the retrieval of intentions is signaled by a specific event (Graf & Grondin 2006: 8, Atrance & Jackson 2009: 381). For example, you might plan to tell someone a message when you meet them, or place things you intend to take with you tomorrow by the door. In time based prospective memory tests, retrieval is signaled by a specific chronological time or duration, for example at 2:00 pm, in ten minutes or within the next hour (Graf & Grondin 2006: 8, Atrance & Jackson 2009: 381).

Early humans probably had no chronological devices to measure time. Linguistic markers of time and tense may also have been absent. So time based prospective memory was probably not an option for them. This does not mean they had no sense of time or duration. They could have ‘temporally tagged’ events sequentially based on regular environmental conditions, such as the diurnal cycle, or behavioural markers, in the sense of acting before or after doing something else. Whatever the case, early humans may have relied on event based prospective memory to control fire.

Prospective memory is measured differently in humans than animals. In humans it requires some kind of future thinking: “it is understood as a form of long-term memory referring to remembering to carry out an action at an appropriate future moment”. In animals “it refers to an animal’s use of short term or working memory in tasks that involve delays between the stimulus and the opportunity to respond” (Raby & Clayton 2009: 315). Researchers are trying to measure how long an animal can hold information in mind, not how they retrieve information at the appropriate moment.

Prospective memory places costs on attention and control over action, in that intentions must be retrieved and other tasks interrupted. Evidence from event based prospective memory experiments suggest remembering to perform an intended task requires conscious attention to retrieve the intention (Smith 2003: 358). While the retrieval of a delayed intention may occur
automatically, some scholars have proposed that prospective memory performance is never automatic (Smith 2003: 349). I will argue that prospective memory would have been adaptive for fire users because it would have allowed them to organize the day’s activities more efficiently.\footnote{In a personal communication, Thomas Wynn pointed out to me that planning to do something a few hours from now is different from imagining a future situation that motivates action in the present. As such, while prospective memory would have been adaptive in the context of controlled fire use, it may not have been necessary to succeed at fire related tasks if foresight sufficed.}

In summary, inhibiting responses, anticipatory planning, delayed gratification and prospective memory are all considered behavioural indicators of executive control. They are associated with executive or conscious control over action, and the ability to form detached representations that can motivate behaviour in the absence of proximate stimuli.

### 7.5 Detached Representations

“Human Behaviour is often directed towards the attainment of some explicitly represented state-of-affairs…not closely related to their current needs and current situation” (Amati & Shallice 2007: 359-360). We can form detached representations that are not directly tied to the perceptual system (Suddendorf & Corballis 2007: 300). These can function as “motivational mechanisms that are not based on drives and sensations” (Sterelny 2003: 4). Their defining feature is that they are context-independent in contrast to cue or stimulus-bound representations (Gärdenfors 2008: 52). Similarly, Sterelny notes that ‘decoupled representations’ “function to track features of the environment, and are not tightly coupled functionally to specific types of response” (Sterelny 2003: 30-31). For example, we might monitor the behaviour of a suspected cheat or the depletion rate of a spatially finite resource without responding to the information being acquired. Detached representations may be cast in language, or as visual images or memories of personal experiences (Geary 2007: 308).
Representing future goals, and inhibiting responses in pursuit of them, requires the ability to form detached representations. Planning ahead involves mentally reconstructing the desired future outcome and suppressing immediate drives in favor of the future reward (Osvath & Osvath 2008: 661). Detached representations function to motivate action in the absence of any direct reference to the future goal, and to inhibit responding to more immediate drives and opportunities. Mammals and birds can consciously represent their current situation and recall salient context specific information on which they can act. However, their behaviour can mostly be explained in terms of direct somatic or environmental signals initiating a response, such as hunger or the presence of a predator.

Detached representations can be defined functionally as representing, or recalling, information without any direct perceptual, physiological or associated indexical, or iconic, sign referring to the information. For example, representing information about fuel, its location or type, and why you need it, and acting on this information when the need for fuel was not immediate and fuel was not present. The cognitive functions of detached representations are that they can motivate behaviour in the absence of direct intrinsic or extrinsic stimuli. They also allow humans to reflect on, or consider, alternatives and consequences beyond their immediate circumstances (Gärdenfors 2008 passim, Brick & Gärdenfors 1999 passim).

Detached representations are hard to identify without verbal report. However, they are implied by future directed self-regulation, and thus can be inferred from the criteria that identify the executive functions described in section 7.4 above. They also enable the human forms of social cognition and cooperation discussed in section 7.6 below, and so can be inferred from the criteria for distinctively human social cognition.

In a simple model of human action, detached representations serve to both motivate and inhibit behaviour. A detached representation might refer to a future goal, a common goal, the intentions of others, or an emotional association with something, such as a situation to be avoided or attained. For
example, representing myself cooking, being warm or running out of fuel later in the day might motivate me to gather fuel in the present. Detached representations can be thought of as the reasons, or intentions, motivating behaviour when proximate cues or stimuli are not sufficient to induce motivation, or need to be overridden.

Detached representations imply the kind of complex intentional psychology associated with human minds and behaviour today. We interpret our own behaviour and that of others in terms of intentions and beliefs (Tomasello 2009 *passim*, Penn et al. 2008 *passim*). People act because they *want* something, and they *believe* they can attain their desires by acting in a certain way. For example, I might infer that an individual gathers fuel because she wants to cook and believes that the fire will go out if fuel is not gathered and added to the fire. Thus, individuals believe they cannot cook without fire and so gather fuel because they want to cook. Being able to understand the covert intentions of others, and share intentions with them, depends on our capacity to form detached representations.

### 7.6 Social cognition

Emery and Clayton propose, “Thinking about why social cognition evolved and what it is used for may provide useful clues as to how we can begin to investigate the potential mechanisms of social cognition” (2009: 88). This section discusses aspects of human social cognition that I will argue are implied by fire use. Successfully engaging in fire related tasks, such as accessing fire, gathering fuel, transporting fire, and cooking, would have involved several individuals collaborating and coordinating their behaviour. Ronen has proposed (Ronen 1998: 443-444) that fire use was necessarily a social activity involving coalitions of cooperating individuals. This could have involved working together or divisions of labour to attain a common goal, or cooperating with members of other groups to access fire.

Being a social activity, fire use involved not only knowing when and how to enact a fire related task, but also *who* was going to enact it. In general, fire use involved knowing how others were going to respond in particular
situations, and that they would respond appropriately when required to. Individuals might expect that others would help them gather fuel, access fire, transport fire and refrain from stealing food. They might expect to be given fire if they needed it, or that others would tend the fire while they were absent. I suggest that fire use implies social expectations and obligations, and intersubjective communication beyond that evident in other primate societies.

Broadly construed, social cognition refers to the sum of processes that allow members of the same species to interact, or the cognitive faculties involved when individuals interact (Steiner & Stewart 2009: 527, Frith & Frith 2007: 274). Alternatively, we can define social cognition more rigorously as the cognitive processes that govern acquiring knowledge of social norms and normative behaviours, and implementing this knowledge in social situations (Steiner & Stewart 2009: 527). In this latter sense human social cognition is markedly different from that of other animals in that “all human cognition is social cognition” (Steiner & Stewart 2009: 527. The ontogenetic development of human cognition depends on being exposed to language, human society and culture (Tomasello & Rakoczy 2003: 121-122). My concern is with three aspects of social cognition that are evidently unique to humans: understanding the beliefs and intentions of others, collective intentionality, and intersubjective or collaborative communication.

Human modes of cooperation and communication require a humanlike belief-desire psychology that is not evident in our closest biological relatives (Call & Tomasello 2008: 187). As Tomasello points out, human sociality required the evolution of “some serious social-cognitive skills and motivations for coordinating and communicating with others in complex ways involving joint goals and coordinated division of labor among the various roles” (Tomasello et al. 2009: 54-55). Complex culture requires and fosters complex social cognition and motivations that are not evident in other animals. Humanlike collaborative activities that provided early humans with an advantage over other apes and hominins can help us understand how human cognition, culture and language evolved (Tomasello 2009: 77).
7.6.1 Human Cooperation in the Middle Pleistocene

Collaborative behaviours such as hunting, mutual defense or cooperative breeding would have been adaptive for early humans, although we do not know when early hominins began to engage in these behaviours. There is evidence suggesting that some Middle Pleistocene humans were proficient hunters from around the beginning of the Middle Pleistocene (Rabinovich et al. 2008). It is also reasonable to think early humans worked together to ward off predators or rival groups (Sterelny 2007: 720). Unlike fire related tasks, both these behaviours tend to be directed at immediate rewards derived from proximate motives.

Cooperative breeding involves individuals other than parents, such as a mother's mother, a brother or sister, or perhaps not a close biological relative, investing in the rearing of the young (Hrdy 2009 passim). This behaviour involves investing in the future. Cooperative breeding may also have a deep history in humans, given the behaviour is common in human societies and the cost of rearing large brained young. Dubreuil has argued (2010: 55) that *Homo heidelbergensis* was engaging in risky longer-term public goods games connected to feeding and breeding, with implications for the cognitive abilities at issue. However, we cannot be sure when this behaviour evolved, nor how it was organized, in early humans. Middle Pleistocene fire use may be the earliest collaborative behaviour we know of involving delayed reciprocity, complimentary roles and group action directed at a future reward. Cooperative breeding would have been highly adaptive in a fire using society (Wrangham & Carmody 2010: 194), and may not have been a viable breeding strategy prior to the emergence of home bases.

7.6.2 Understanding and Detecting Intentions

Chimps are evidently good at using social knowledge for selfish motives; however they display no clear evidence of prosocial behaviours (Hirata 2009: 3). There is virtually no evidence for the kind of cooperative

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24 The transition from tree to ground sleep (Coolidge & Wynn 2006) or the evolution of adaptations for accurate throwing (Calvin 2004: 94-96) may provide clues as to when collaborative defensive strategies may have evolved and the form they took.
social interactions on which human societies are founded (Herrmann et al. 2007: 1365). Chimpanzees tend to be selfishly motivated. In general, they do not help others even when providing help is cheap (Tomasello 2009: 5). For example, chimpanzees will not help a distressed infant looking for her mother, although they know why the young chimp is distressed and where the mother is (Tomasello 2009: 5). Human social cognition is founded in two abilities that are arguably uniquely human; understanding the intentions and beliefs of others, and representing triadic relations (Saxe 2006: 235).

Humans can infer the covert mental states of other humans and understand these as distinct from their own mental states. We understand the beliefs and intentions of others and know that others can have false beliefs. Scholars refer to this ability variously as a theory of mind (Ang & Pridmore 2009: 117), mental state attribution (Penn et al. 2008: 109), intentionality detection (McCabe et al. 2000: 4405), intersubjectivity (Gärdenfors 2008: 52), and ‘mindreading’ (McCabe et al. 2000: 4404). The extent to which the intentions of others can be represented and kept distinct from one’s own is the critical aspect of human social cognition that enables language and culture (Knoblicht & Sebanz 2008: 2021).

Mental state attribution can be perceptual, knowing what another sees or hears, motivational, knowing what another wants, and informational, knowing what another knows or believes (Emery & Clayton 2009: 88). Informational theory of mind is more cognitively demanding because what others know or believe is often covert, unlike perceptions and motivations that can be inferred from the context or situation. Similarly, Gärdenfors identifies (2008: 52-54) five aspects of intersubjectivity: representing the emotions, desires, attention, intentions, and the beliefs and knowledge of others. He avoids the term ‘theory of mind’ as this generally refers only to representing the beliefs of others, which is “but one aspect of intersubjectivity” (Gärdenfors 2008: 52). Understanding the beliefs and knowledge of others enables human forms of cooperation involving shared intentions directed at future benefits (Gärdenfors 2008: 52, 60).
Understanding that others have their own intentions and beliefs allows humans to appreciate the significance of triadic relationships: individuals jointly attending to, and communicating information about, a third party, an object or a feature. Hurford defines (2007: 205) triadic communication as, communicating a message to a receiver about some third entity, an object or event in the outside world. For example, we might decide to access fire or gather fuel, and need to communicate pertinent information concerning our task, such as the direction we shall travel or the location of a fuel source.

Understanding triadic or intersubjective communicative acts involves individuals collaboratively attending to, working toward or referring to some other object (Saxe 2006: 235). Even something as straightforward as pointing out a food source or a fuel source, “provided it is intentionally produced in an intersubjective field of joint reference, can be regarded as a kind of ‘protosymbolic’ communication” (Sinha 2004: 224). This involves what Tomasello and Carpenter call ‘shared’ or ‘we’ intentionality, which they describe as “collaborative interactions in which participants share psychological states with one another” (2007: 121).

If groups of individuals, rather than pairs, have common future goals and adopt complimentary roles to attain them, then we can refer to ‘we-mode collective intentionality’ (Tuomela 2007: 3-7). Understanding and sharing intentions enables human language, culture and cooperation. Cooperative communication, future directed collaboration and instructed learning all depend on these basic human social cognitive skills. Tomasello has argued (2009: 77) that human collaborative activities are the key to understanding how many uniquely human qualities evolved. Fire use is particularly pertinent with respect to the evolution of human cooperation because fire related tasks would have been very difficult unless individuals cooperated in complex ways that are not evident in the cooperative behaviours of other animals.

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25 Shared intentionality derived from joint attention usually refers to two participants sharing an intention. Sharing intentions with a few individuals or at the group level is referred to as collective intentionality, although the distinction is not always made clear in the literature on human social cognition.
Human cooperation often involves ostensive signalling: getting another’s attention in a way that lets them know the message about to be sent is meaningful (Frith 2008: 2037). It requires predication, referring to some feature about the object of shared attention (Tomasello 2003: 94-95). Cooperative behaviours may also require informing another person or persons of one’s intention toward the thing being attended to, although this may be understood depending on the communicative context.

The intentional psychology of collective action is supported by the following kinds of information: (1) each actor intends that they enact a particular behaviour; (2) they each intend to do their part; (3) they each believe others intend to do their part; and (4) they each intend to do their part because they believe this (Pettit & Schweikard 2009: 23). These are rational constraints on the possibility of collective intentionality (Toumela 2007: 5, 2006: 37). An agent needs to believe not only that she can perform a role to bring about X, but also that others believe they can perform their part and that they intend to perform it (Toumela 2007: 5, 2006: 37). Understanding the beliefs and intentions of others toward third parties, and acting on this understanding in pursuit of mutually beneficial future goals is one reason why collective action is cognitively demanding. Collective intentionality allows individuals to recognise that an interest is mutually beneficial and that they need each other to secure the benefit (Tomasello 2009: xvii).

Collective intentions establish the required referential context for linguistic communication to take place. Recognising that signals are signals, and so convey meaning, is a critical feature of deliberate and conscious signalling (Frith & Frith 2007: 274). Communicators need to understand each others intentions to convey information. Before language could evolve early humans had to recognise signals as being intentional and meaningful (Sinha 2004 passim). Tomasello has argued that ostensive signalling, and predication, grounded in practical action, rather than displacement, was the first step toward language (2003: 94-95). Others have suggested that a need to refer to displaced phenomena facilitated the initial stages in the evolution of language (Bickerton 2009 passim, Deacon 1997 passim).
7.6.3 Trust, Tolerance and Cooperation

Humans are far more trusting, tolerant and cooperative than other mammals (Tomasello 2009: 74). We rely on other people, and expect them to behave in certain ways, and know they hold similar expectations of us (Tomasello 2009: 186). We tolerate and interact with strangers and we suppress individual emotions and desires so as to keep the peace, to avoid sanctions, for the good of the group or to maintain our reputations. Humans collectively sanction or punish intolerant, untrustworthy or uncooperative individuals whose attitudes and actions destabilise social coherence and the provision of public goods (Tomasello 2009: 186, Hauert et al. 2008: 114, Sterelny 2007: 723, Fehr & Gächter 2000: 980).

Collaboration is a kind of cooperation in which participants share a common goal that cannot be realised unless individuals work together and participants take reciprocal or complementary roles in order to achieve the goal. When humans collaborate, participants are generally motivated and willing to help one another accomplish their role if needed (Moll & Tomasello 2007: 2). The hunting behaviours of social carnivores and chimpanzees can be considered collaborative in a restricted sense because participants need not understand the intentions of others or help others fulfil their role, and action is directed at a proximate reward. This kind of collaboration, or 'mutualism', is common in animal societies where cooperators receive an immediate benefit (Stevens & Hauser: 2004: 60).

A key distinction between human cooperation and that of other animals is that our mutual goals are often in the future, and lacking a perceptual or intrinsic point of reference (Brinck & Gärdenfors 2003: 484). Human goals are often displaced in time and space and often involve individuals acting remotely from each other. Spatially or temporally remote goals need to be represented without any intrinsic reference to the goal, and the time until the goal is realised discounted against more immediate potential rewards. I will argue that most fire related tasks provide good evidence for future directed cooperation.
Human cooperation is different from the cooperative behaviours some other animals engage in, including eusocial insects, in the ways listed below (Kappeler & Van Schaik 2006: 14-16). Fire use is interesting in this respect because fire related tasks arguably required these aspects of human cooperation. I suggest that humanlike modes of cooperation would have enhanced the inclusive fitness of individuals in fire using groups by ensuring regular access to fire and improving the efficiency of fire related tasks.

1. Whereas most cooperation in nature operates at the level of dyads, humans commonly engage in group-level cooperation. Undertaking group level cooperation beyond dyadic interactions poses more serious cheater detection problems.

2. Humans engage in extremely high-risk cooperation, such as war, much more than other animals.

3. Humans tend to cooperate with non-kin far more than do other animals, including eusocial species like bees and ants among which all members of a colony are closely related.

4. Humans are willing to incur costs to punish non-cooperators who undermine cooperative efforts. Free riders risk the breakdown of all cooperative effort. There is currently no evidence that any other animals punish defectors. Some animals and plants engage in “punishment” (West et al. 2010: 25), but they do not monitor or punish free riders as far as we know. Punishing cheaters, free riders and defectors depends on the establishment and enforcement of social norms.

5. In human societies reputation facilitates reciprocity, more so than in animal communities. Reputation is vital for an individual’s social success.

6. Humans exchange goods and services (including information) whereby value is determined by the commodity being exchanged.

This kind of cooperation involves social motivations and executive cognitive skills that are evident in humans, but not in our primate relatives (Hirata 2009: 3, Tomasello 2009, Tomasello et al. 2009, Herrmann et al.
The cognitive complexity of a cooperative endeavour increases if the collaborative effort is directed toward a future goal, involves a division of labour or complimentary roles are conducted separately from each other in time or space (Tomasello 2009: 186).26

Cooperation is considered cognitively demanding when it is directed at a future reward, because the reward must be represented and time will be discounted (Gärdenfors 2008, Stevens & Hauser 2004). Delayed or indirect reciprocity also increases cognitive demands because it involves tracking and remembering who owes what to whom over time and space (Gärdenfors 2008, Stevens & Hauser 2004). If collaboration involves divisions of labour or individuals acting remotely from each other, then individuals need to know what others are doing and that others can be trusted to fulfil their role (Tomasello 2009: 204, Tuomela 2006: 37). “Firm evidence of reciprocity in animal societies is rare and many examples of cooperation between non-kin probably represent cases of intra-specific mutualism or manipulation” (Clutton-Brock 2009: 51).

The cognitive demands of cooperating in humanlike ways require social cognitive skills that are not evident in the other apes (Herrmann et al. 2007, Stevens & Hauser 2004). These include self-awareness, informational theory of mind, collective intentionality, response inhibition, trust and tolerance, intersubjective communication and monitoring free riders (West et al. 2010: 25, Tomasello 2009 passim, Herrmann et al. 2007 passim, Stevens & Hauser 2004 passim). Human cooperation directed at future mutually beneficial rewards is logically dependent on these uniquely human social cognitive skills. Thus, behaviours involving human cooperation can stand as reasonable grounds for inferring these cognitive abilities were operational.

26 Some other species, including chimpanzees, engage in cooperative hunting behaviours. However, this arguably does not involve any kind of we-mode collective intentionality (Tomasello 2009: 63). There is little evidence that the behaviours of other hunting species involve directing action toward goals other than immediate rewards (Barkley 2001: 14). Stanford notes (2001: 52) that chimpanzee hunters do not seem to be actively cooperating with each other to bring about the kill.
7.6.4 Public Goods and Social Dilemmas

Social dilemmas and providing public goods can help us understand the emergence of the cognitive skills that govern human cooperation and our prosocial tendencies. Many scholars think that complex cognitive abilities emerged to support cooperation, detecting free riders and social cohesion (Cortina & Liotti 2010: 293, Gamble et al. 2010: 118). Cognitive limitations that exclude reciprocal exchange, understanding intentions and attending to future rewards can probably account for why non-human apes cannot cooperate in humanlike ways or maintain public goods (West et al. 2010: 25, Stevens & Hauser 2004: 64). Understanding the puzzle of human cooperation, human ultra-sociality and our tendency towards strong reciprocity, lies in the evolution of adaptive early human behaviours that involved providing public goods and resolving social dilemmas. I suggest that fire use is highly conspicuous in this respect.

The social dilemma refers to a broad range of social situations that meet the following conditions: “Each individual is better off acting in their immediate self-interest, yet, if all individuals act according to their self-interest, then everyone will be worse off” (Van Vugt & Van Lange 2006: 238). In these situations, defectors are better off, but if everyone defects then individuals would have been better off if they cooperated (Hauert et al. 2008: 115). Most fire related tasks imply social dilemmas. For example, it is in one’s own interest to avoid gathering fuel, hostile confrontations, carrying fire or tending the fire. All these activities required time and energy better spent by an individual resting, or looking for food and mates. It would also be in the interest of individuals to steal food, fuel and fire from others whenever they could. However, if everyone behaved like this, then everyone in the group will miss out on the benefits that fire provides.

Public goods imply social dilemmas. A communal fire was a public good in that exclusion was very costly or impossible, and one individual’s consumption does not diminish returns for others (Ofek 2001: 146). The problem with public goods is that they will be undersupplied without some incentive other than the good itself (Ofek 2001: 146, Hawkes 1993: 342).
Evidence consistently demonstrates that individuals require positive or negative incentives to encourage them to contribute toward the cost of maintaining a public good (Hauert et al. 2008: 115, Fehr & Gächter 2000 *passim*). The problem of free riding is such that in modern economies governments typically provide public goods that are paid for through compulsory taxation (Ofek 2001: 146). The collective action required to provide a public good and resolve social dilemmas is cognitively demanding because it involves tempering individual drives and motives in favour of the common good, monitoring contributions, and detecting and sanctioning free riders. It may also involve divisions of labour and complementary tasks conducted remotely (Sterelny 2007: 725).

### 7.7 Behavioural Criteria

From the above discussion I propose that the following behavioural criteria imply a range of distinctively human cognitive abilities. The arguments in Chapters Eight and Nine are that these behaviours can be inferred from the fire related tasks and problems discussed in Chapters Five and Six, given the conditions described in Chapters Two, Three and Four.

*Inhibiting responses:* Inhibiting prepotent, habitual or selfish responses. Response inhibition is cognitively demanding because it involves suppressing, overriding and regulating responses to proximate intrinsic and extrinsic stimuli that induce strong motivations to approach or avoid a goal. Inhibiting responses may be required or adaptive if a routine behaviour is no longer effective or appropriate, to refrain from behaviours with negative future consequences, to ignore interference that disrupts an ongoing activity, and to refrain from selfish behaviours that undermine cooperative efforts and social cohesion. Response inhibition implies executive control over action involving an extended working memory capacity.

Foregoing a proximate reward to ensure that a greater remote benefit is attained requires inhibiting responses. Delayed gratification, consumption or reciprocity are cognitively demanding because they involve representing remote benefits and inhibiting responses to more immediate benefits and
tolerating any discomfort associated with missing out on proximate rewards. Delaying gratification is required or adaptive if attaining the future reward ensures the survival, or increases the fitness, of individuals. Delayed gratification implies executive control over action, involving an extended working memory capacity and detached representations.

*Anticipatory planning:* Preparing for a future need when not experiencing any direct internal or external stimulus associated with the need. Planning in advance is cognitively demanding because it involves, representing the future goal and regulating proximate motives that may interrupt or prevent the goal being realised. It is required or adaptive if it allows individuals to procure and take advantage of benefits that cannot be attained through the mechanisms governing future directed behaviours in other animals or by responding to proximate cues. Anticipatory planning implies executive control over action involving an extended working memory capacity, detached representations and episodic memory.

*Future Directed Group Level Cooperation:* All or most members of a group collaborating and coordinating their behaviour to attain a goal or ensure an ongoing benefit. Group level cooperation is cognitively demanding if it is directed at a future reward, involves a division of labour, or involves individuals acting remotely from each other. This kind of cooperation requires sharing attention and intentions, understanding the intentions of others, trusting others to fulfil their role and knowing they similarly trust you, communicating information about displaced situations, goals or individuals, and discouraging free riders. It may also involve reciprocity and monitoring the reliability of others. Group level cooperation allows individuals to take advantage of benefits that they could not secure alone because of practical or economic constraints. Humanlike group level cooperation implies inhibiting responses, delaying gratification, anticipatory planning and requires an informational theory of mind, collective intentionality and an intersubjective means of communicating information.
Providing a public good: Providing a benefit that individuals can take advantage of without incurring provisioning costs because the cost of excluding them is too high. Public goods maintenance is cognitively demanding because it requires monitoring, detecting, discouraging and transmitting information about free riders. Public goods can greatly improve the inclusive fitness of individuals with access to the good if those providing the good are not disadvantaged. There are probably only three strategies that suffice to ensure the continuing supply of a public good that is economically costly to maintain. Those who do not provide the good compensate those that do, or those that do not contribute are excluded from the good, or the threat of sanctions discourages most individuals from free riding. Maintaining a public good implies culturally transmitted social norms, values and obligations from which we can infer an informational theory of mind, collective intentionality and an intersubjective means of communicating information.

7.8 Summary

I have identified a range of behaviours that imply human cognitive abilities. My focus is on self-regulation directed towards future outcomes and future directed group level cooperation. Demonstrating self-control in a specifically designated context provides a decisive test for the ability to plan ahead and inhibit responses (Osvath & Osvath 2008: 663). Individual desires and future goals often conflict with social expectations or impulsive urges for immediate gratification (Wittmann & Paulus 2007: 7). “Regulating internally generated impulses is therefore an important ability for accomplishing goals and instructions as well as complying with social norms” (Rueda et al. 2007: 29). Behaviours involving future directed self-regulation, such as inhibiting responses, delaying gratification, anticipatory planning, group level cooperation and providing a public good provide good evidence for a range of human cognitive abilities. These include an extended working memory capacity, episodic memory, detached representations, informational theory of mind, collective intentionality and intersubjective communication. If solving fire related problems required behaving in these ways, then controlled fire use provides grounds for inferring these aspects of cognition.
Chapter Eight: Inferring Executive Functions from Fire Use

8.1 Introduction

Fire related tasks provide good evidence for extended working memory capacity, episodic memory and detached representations. This is because these tasks imply inhibiting responses, delaying gratification and anticipatory planning that indicate these executive functions. I begin by arguing that solving fire related problems involved inhibiting responses and delaying gratification. I then argue that some fire related tasks involved anticipating and preparing for a future need. In both cases I will consider possible objections. The focus of this chapter is the role of future directed self-regulation in solving fire related problems.

In some hypothetical situations we can make a strong case that a cognitive process was required to use fire. However, as we cannot know exactly what strategies were used, I propose that in all the situations discussed below individuals with these executive functions were more likely to succeed at a fire related task than individuals without, placing the former at an advantage over the latter. This is an important consideration if fire users were in competition with each other, and if it increased an individual’s capacity to solve fire related problems.

8.2 Inhibiting Responses and Delaying Gratification

Response inhibition directed at future rewards is the hallmark of executive functioning (Verbruggen & Logan 2008: 418). This section argues that we can infer response inhibition and delaying gratification from maintaining fire, cooking and accessing fire. Inhibiting responses is important for humans when habits have to be overridden, when we must not act in ways we want to or act in ways we do not want to, when ignoring distractions, when switching tasks and when routine behaviours do not suffice (Aron and Poldrack 2005: 1285).

Response inhibition is cognitively demanding if individuals must suppress responses to proximate rewards in favour of future ones. Declining the immediate satisfaction of one drive in favor of a future oriented one is a
taxing planning situation requiring rejection, patience, and tolerating the discomfort of not getting the immediate satisfaction (Osvath & Osvath 2008: 663). In such cases effortful cognitive control is required to inhibit responding to more immediate goals or desires (Barber & Carter 2005: 899). I begin by describing the kind of responses that I suggest fire users sometimes had to inhibit, and then relate these situations to fire related tasks.

Sometimes fire users were better off inhibiting desires or compulsions to seek food, water or mates, to groom, rest or make a tool, if these interfered with the initiation or continuation of a critical fire related task. I am assuming that these stimuli induced strong prepotent motivations in Middle Pleistocene humans. The rewards these behaviours offer would have provided individuals with immediate gratification, except perhaps tool making. A fire user intent on enacting a fire related task might have to inhibit responding to hunger, thirst, an available food, a preferred food, a mating opportunity or fatigue. They may also have had to inhibit responding to opportunities to groom, play, make a tool or intimidate competitors and subordinates.

This is not to suggest fire users always had to inhibit such responses. A fuel gatherer may stop to eat some fruit then continue looking for fuel. However, often enough gathering fuel would have conflicted with more immediate desires, and fuel gathering would not always have been the attractive behavioural option. Importantly, being able to interrupt and return to an ongoing activity or switching from one behaviour to another is suggestive of the enhanced behavioural flexibility associated with extended working memory capacity (Hallos 2006: 175).

I am assuming that keeping a fire going was more important than sometimes going hungry, missing out on a mating opportunity or socializing. Of course, eating and mating are the basis of survival, which is why we can assume Middle Pleistocene humans were strongly motivated to respond to these fundamental needs. However, keeping the fire going would have improved the inclusive fitness of all group members even if some individuals sometimes missed out on a meal or a chance to mate.
8.2.1 Fuel Gathering

What motivated fire users to gather fuel if there was no immediate incentive to and other rewards were on offer? While the reward for gathering fuel was considerable, it was often delayed (Ronen 1998: 443-444, Goudsblom 1989: 165). In these cases, detached representations of the future goal are required to regulate responses to prepotent and proximate rewards (Gärdenfors 2003: 5). Detached representations would have been sufficiently cogent to motivate individuals to choose a future goal over a more immediate reward. Imagining the future outcomes to be attained or avoided is a critical capacity that allows for future directed self-regulation (Barkley 2001: 5-8) in the absence of proximate motivating stimuli.

Fuel gatherers faced three problems that sometimes would have required inhibiting responses and delaying gratification. First, often fuel gathering would coincide with more desired proximate opportunities. Second, fuel gathering for the most part offered only delayed rewards (Ronen 1998: 443-444, Goudsblom 1989: 165). This is in contrast to other early human behaviour, including tool use, which for the most part was probably closely correlated with proximate needs (Ronen 1998: 441). Third, fuel gathering was often a labourious task that took time and energy, and sometimes would have increased the risk of injury or being preyed upon. It is the sort of behaviour individuals might prefer to avoid if they could.

Fuel gathering would often have conflicted with proximate rewards because Middle Pleistocene humans did not always live in Edenic conditions. No doubt they experienced times when resources were abundant, and when time and energy constraints were relaxed. In these times it would have been easier for individuals to satiate their more immediate needs and find time to gather fuel. However, it is unlikely that these were the prevailing conditions for Middle Pleistocene foragers in most habitats.

We know that non-human primates and human foragers regularly experience seasonally related nutritional stress (Pruetz & Bertolani 2009 passim, Jenike 2001: 216). Competition for mates is usually intense in both
human and primate societies and all primates, including humans, spend a large percentage of their time maintaining social relationships (Lehmann et al. 2007 *passim*). We also have evidence that Middle Pleistocene humans faced resource shortages due to the over exploitation of a single patch (Rivals 2009: 335-337). For the fire users of northern Europe and Asia a blanket of snow raises the winter search costs for many resources at a time when more food and more fuel is required because of the increased cost of thermoregulation (Stiner 2002: 32), and daylight hours were reduced (Hill 2003: 279).

Middle Pleistocene humans lived in various habitats from open tropical grassland to temperate boreal forest. Conditions in these habitats would have fluctuated in different ways. Sometimes conditions, such as seasonal change, extreme heat or cold, or a scarcity of resources, would have made survival difficult. To generate the spare time required to avoid conflicts of interest Middle Pleistocene humans would have had to be more efficient at extracting energy from the environment than foragers with modern cognitive skills given that modern human foragers cannot avoid nutritional stress.

All things considered, it is reasonable to infer that Middle Pleistocene humans did not always have easy access to resources and that the time and energy budgets of these humans were regularly constrained. While early humans may have sometimes experienced Edenic conditions it is unreasonable to think these conditions dominated throughout the Middle Pleistocene. We have positive evidence to suggest that many Middle Pleistocene fire users would have experienced unfavourable environmental conditions (Shen et al. 2009: 198, Preece et al. 2007: 1282, Mania & Mania 2005: 103).

Therefore, it is reasonable to think individuals would have had to gather fuel when fuel, food or mates were scarce, or when rain, snow, extreme heat or limited daylight hours reduced foraging and fuel gathering time. Fire users also had to deal with other contingencies, such as the presence of predators or humans from other groups, rain, births, deaths and maintaining social relationships. For example, hungry individuals may have
had to continue looking for fuel, or pass up mating opportunities to ensure enough fuel was gathered to cook, be warm later in the day or keep the fire going. Choosing between proximate and remote rewards, or overriding prepotent responses to proximate rewards, is cognitively demanding and involves future directed self-regulation.

Sometimes fire users could have satisfied immediate urges and managed to gather fuel. However, my claim is that conflicts would have occurred often enough that individuals who never inhibited responses would often have failed to gather enough fuel. In difficult conditions, such as during winter or if food was scarce, delaying gratification was probably required to ensure the fire did not go out. However, as fire users would often have faced conflicts of interest being able to inhibit responses, delay gratification and interrupt behaviours would have been adaptive in all fire using contexts.

One objection to this claim is that proximate incentives were sufficient to motivate fuel gathering. If fire users only gathered fuel when they needed to use the fire, say to cook or be warm, or to prevent the fire’s imminent demise, then the reward was not delayed. I am assuming here that preventing a fire from going out in urgent situations provided individuals with some immediate emotional relief or satisfaction, although the goal to cook or be warm could still have been remote. If fuel gathering was motivated by a proximate reward, conflicts were less likely to arise.

Gathering fuel in response to these kinds of proximate needs would have worked if fuel and other resources were always abundant and close by, and if the need to gather fuel always arose at a convenient time of day. Early human fire users would have prepared and tended fires when needs arose, as do modern foragers (Mallot et al. 2007: 2037). However, this considers only a narrow range of the conditions Middle Pleistocene fire users would have encountered. If fire users did not prearrange for fuel to be always close at hand, or for fuel to always run out at a convenient time, they could have run out of fuel at anytime. This means fuel would sometimes have run out, or the fire would be needed, at a time when fuel was difficult or impossible to
gather, for example at night, in harsh climatic conditions, when predators were threatening, or if fuel was not close at hand.

Of course individuals could try and gather fuel in the dark, during a storm or with predators on the prowl. Chimps are known to travel and forage on brightly moonlit nights (Pruets & Bertolani 2009: 260), and early humans could have searched for fuel in such conditions. However, these conditions do not always prevail, nocturnal activities are rare for diurnal primates, and the chimps in question were under some ecological stress from high midday temperatures and scarce resources (Pruets & Bertolani 2009: 260). In these situations fuel gathering would have been risky, less efficient and less effective. This means the chance of success would have been reduced. Ironically, gathering fuel in these conditions implies that individuals inhibited fears or aversions to predators and moving around at night.

Another problem with this objection is that responding to a proximate need to use fire would not always have removed the need to inhibit responses. Hungry fire users who were only motivated by proximate needs will look for food. When they find food they will then be motivated to eat or cook the food. Once they have eaten, individuals no longer have a proximate motive to cook, thus they have no proximate motive to use the fire. Sometimes cooks either gathered fuel when they were hungry and wanted to cook, or they gathered food with no immediate need to cook, which both imply that individuals could inhibit responses and regulate their behaviour with the future in mind.

It is also unlikely that the need for warmth or light provided an immediate need that regularly motivated fuel gathering. A fire’s warmth and light are both most adaptive at night, when temperatures drop below zero or when individuals are more prone to predation. To have warmth or light

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27 Early human fire users probably did not use torches or flaming branches to look for fuel at night. Producing an effective torch requires complex technological knowledge and preparing the materials in advance. This implies cognitive abilities beyond those I am suggesting were required. Fire brands burns quickly and as such make relatively ineffective search lights.
throughout the night required that enough fuel was gathered prior to it becoming dark. If individuals waited until it was cold and dark, that is when the need was immediate, then they had to gather large amounts of fuel at dusk or after dark. Thus, an immediate need to be warm or have light is unlikely to have regularly motivated fuel gathering at convenient times.

Gathering fuel only when you need to would have been much less efficient if individuals only gathered enough to meet their immediate needs. This is very probable if individuals were only focused on their immediate future. However, this implies that individuals made more trips carrying lighter loads. Central placed foraging models consistently show that it is better to return with large, rather than small, items even when the latter are more proximate and more easily procured (Winterhalder 2001: 22).

Another problem with trying to regulate fuel gathering in response to the fire’s imminent demise is that it would not always have been clear when the fire was about to go out. This is not simply a matter of gathering fuel when gathered supplies ran out because a fire may continue to burn for hours or days after this had occurred. It is not always clear when a pile of hot ash or a smouldering log is about to become just a pile of ash or a charred log. Thus, it would have been difficult to estimate exactly when the time of urgency had arrived. If individuals were foraging, grooming, making tools, resting, watching over children, or simply not attending to the fire, then they could easily fail to notice the fire was about to go out.

Some scholars suggest that fuel gathering was triggered by stimulus-response associations that motivated individuals to enact relatively automatic procedures (Coolidge & Wynn 2007: 81). When the appropriate cue was perceived, or contextual trigger established, individuals would automatically enact a learned fuel gathering procedure. This is how many scholars interpret the behaviour of Middle Pleistocene humans and Neanderthals of the Late Pleistocene (Shreeve 1995: 91, 156).
For the reasons discussed above, it is unlikely fuel gathering could always have been a highly automated response to proximate stimulus in the way that other associatively learned behavioural routines, such as foraging for food and tool making, might have been. One problem is that fuel gathering is not procedurally like foraging or tool making and would often have interrupted these older provisioning systems (Ronen 1998: 444). With foraging and tool use, intrinsic or extrinsic stimuli motivate a sequential or cyclic pattern of events (Ronen 1998: 442), with the various steps clearly linked and perceived by individuals (Ronen 1998: 441). However, fire use implies interruptions, delayed gratification and coordination with other activities. Thus, keeping and using fire is not like other mundane activities early humans engaged in.

Another problem with the idea that fuel gathering was a relatively automated conditioned response is that gathering fuel for the most part offered individuals no positive feedback. Without some kind of positive reinforcement associated with the act of gathering, it could be argued that there was no mechanism for associating a stimulus with a response. Reinforcement catalyzes stimulus-response associations that elicit relatively automated behavioural reactions (Smith 2009: 393). The strength of associations between cues and memories is based on their history of use (Reder 2009: 25). Thus, it is difficult to see how conditioned fuel gathering responses could have evolved, because conditioning requires a history of feedback that fuel gathering would not always have provided if the reward was delayed.

Even in good times, individuals who cannot inhibit responding to proximate rewards will tend to put off fuel gathering until the last minute and would have avoided it altogether if they could, because virtually any other thing we can imagine an early human might do is preferable to gathering fuel. Fuel gathering would often have been a laborious task that it is reasonable to think individuals would rather have avoided. Sometimes it was dangerous work, and sometimes it had to be done in harsh conditions. In difficult times when fire users could least afford the fire to go out, such as when food was
limited or during winter, conflicts of interest would have been more frequent and intensely experienced by individuals.

In summary, fuel gatherers often had to inhibit responses and delay gratification to ensure enough fuel was gathered. If fuel gathering was interrupted, individuals had to remember to return to the task later on. Gathering fuel in response to immediate needs would not always have been possible, and would often have increased the risks and costs associated with fuel gathering, thereby increasing the risk of the fire going out. Conditioned responses initiating relatively inflexible automated behavioural routines are not well suited to fuel gathering and would be difficult to establish without positive or negative feedback.

Resolving the kind of conflicts of interest I have described also implies greater delays than have been detected in tests that measure response inhibition and delayed gratification in human children and animals (Suddendorf & Corballis 2010: 294, Clayton & Russell 2009, Atance & Jackson 2009, Raby & Clayton 2009, Atance & O’Neill 2001). Unlike these tests, fuel gatherers probably had to sometimes delay gratification to acquire benefits that would not have been realised for hours or even the next day. If early fire users stockpiled, then the delay may have been days or weeks. Also, fire users could not perceive the reward that may have been somewhat abstract, such as cooked food, warmth, or preventing a fire from going out. Finally, these tests usually require that subjects simply wait to gain the delayed benefit. However, fire users had to gather fuel to gain the benefit.

8.2.2 Transporting Fire

Transporting fire would have involved sustained attention that was directed at a future goal. Individuals transporting fire, using either a burning log or fire carrier, may have had to inhibit any responses that interfered with the task. They were better off not responding to any needs or opportunities that interfered with the task unless someone else took over their role.

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28 As discussed in Chapter Five and Six, a fire carrier is a hypothetical implement used to transport fire. It does not refer to the individual carring a fire.
Individuals transporting fire needed to take care because if they neglected their task even for a few minutes to investigate something or attend to some other need the fire could go out. Simple fire carriers could have been put down for a few minutes to attend to something else, but the individual would have to remember to return to the task before the fire went out. A smouldering stick or log can go out quickly if it is not kept well oxygenated and so could not have been left unattended for too long.

One possible objection to this claim is that fire users never had to move fires very far. Moving a fire a few hundred meters would not have taxed self-control too much. However, the raw material transport distances (Marwick 2003: 78), ranges (Rivals 2009: 337, Burke 2006: 514), tropic level (Stiner 2002: 33-34) and the forager lifestyle of Middle Pleistocene humans suggest that they often moved distances of up to ten kilometres. If Middle Pleistocene humans were exploiting patches from a central place, then they often would have moved at least twice the radius of the patch they had been exploiting (Grove 2009: 223). If individuals were trying to escape with stolen fire they may have had to move fire a long way fast.

We must also consider early humans walked to get around. If it takes an individual a conservative five minutes to walk one kilometre, then it takes 25 minutes to cover five kilometres. Uninterrupted trips between five to ten kilometres would conservatively take over on hour or more. Early fire users may have moved around incrementally, thereby reducing the cognitive load on attention. However, stopping to make a new fire every 500 meters or so would have been impractical, inefficient and risky if it delayed a necessary move or if the patch they were moving from was depleted of food and firewood. The main reason why any central placed foragers move is because they have exhausted local resources and fire users would often have exhausted fuel resources from a patch they inhabited (Ofek 2001: 157).

Another possible objection could be that transporting fire was so simple that individuals could not fail at this task. This would have been possible if individuals were very experienced at moving fire, which we might
expect they were. However, the simplest means available, such as smouldering logs, or simple fire carriers, are not failsafe and more reliable means, such as fire totes and smouldering wicks, are cognitively demanding to make. Fire carrying utensils would have needed to be fed dry kindling regularly, which would not have been easy in damp environments, and burning sticks and logs need to be kept moving (Wrangham 2009: 193). Individuals had to be mindful of these conditions, lest they stop moving for some reason, forget to kindle the flame or run out of dry kindling. If fire users transported fire any appreciable distance, then this would have involved increased demands on attention, memory and response inhibition.

8.2.3 Using Fire

Inhibiting self-interested desires to steal food or other resources from others would have been adaptive in a fire using society. This is because cooking involves delayed consumption that would have provided stronger individuals with tempting opportunities to take food from weaker individuals (Wrangham 2009: 158-159, Wrangham et al. 1999: 568). This is not a big problem in other primate societies because individuals consume food they find on the spot. However, dominant individuals will tend to take food from subordinates if they can. In a fire using society dominant individuals could have sat by the fire waiting for subordinates to bring in food, or roamed from fire to fire helping themselves (Wrangham 2009: 158-159). This is not adaptive in a fire using context because individuals will not be inclined to bring food to a fire if they cannot trust others to refrain from taking their food. They would also be less inclined to gather fuel for a fire they could not benefit from regularly. “Central placed provisioning presupposes respect for property. It cannot evolve if those bringing resources back are likely to lose them to stronger individuals” (Sterelny 2005: 137).

This probably would have increased the cost of fire maintenance for food stealers. Even dominant individuals would find it difficult to maintain a fire alone and guard their own resources from pilferers. Unconstrained stealing of food or other resources would not have been adaptive for two reasons. First, victims of food theft would not be inclined to help a food
stealer maintain a fire; and second, food stealers need help to keep a fire going and protect their own resources. Food stealing could well have lead to everyone in a group regularly missing out on the benefits fire provides. This is because bullies need some help to keep the fire going, and if they steal from or harass those helping them then these individuals might be less inclined to help.

Coalitions of bullies could have managed to maintain a fire and continue to steal from others. This would have resulted in groups of very well organized individuals who as a group do not steal from each other and can maintain fire while still being able to steal from others. The result would be a system that required socially informed control over desires to steal fire from particular individuals. It would be acceptable to steal from individuals of other groups or sub-groups, but not from members of one’s own fire using coalition. Thus, using a fire to cook probably involved response inhibition.  

Wrangham has suggested that a form of pair bonding regulated the problem of food stealing. Females paired themselves with strong males capable of protecting them and their food from theft. In turn women maintained the fire and cooked the food (Wrangham et al. 1999: 575). Alternatively, coalitions of cognitively well-endowed females could have conspired to see off, or control, a few cerebrally challenged aggressive males (Wrangham et al. [Milton] 1999: 583). Wild and captive chimpanzee females will sometimes form coalitions to stop harassment from overly aggressive males (Rodolf von Rohr et al. 2011: 11). Whatever the mechanism, food stealing was best curtailed in fire using societies and this would have involved inhibiting any selfish desires to steal food. In Chapter Nine I will argue that food stealing would have undermined the cooperation and social cohesion required to maintain and use a domestic fire.

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29 It is reasonable to speculate that controlled fire use would have selected against Alpha males who tried to dominate hominin societies. If fire using was adaptive, and bullies undermine fire use, then coalitions of cooperative individuals could have been selected for as the dominant mode of social organization. Experimental studies consistently demonstrate that punishment promotes cooperation (Shinada & Yamagishi 2007: 330). The implications of this for the origin and evolution of human culture are significant.
8.2.4 Accessing Fire

If stealth or force were being used to access fire, then individuals may have had to suppress fear that prevented them from acting, or urges to act impulsively. Individuals that could act at the right moment would have improved their chance of success. Response inhibition would not have been as important if fire seekers greatly outnumbered the other group. However, if groups were of equal strength, fire seekers were outnumbered or stealth was being used, inhibiting responses probably would have been required. This is because individuals have to take more care and are likely to be more fearful as their chance of injury or death increases. It is difficult to see how raids on other groups could regularly succeed without preparation and executive control over impulsive motivations that induced inappropriate responses.

Response inhibition would also have been adaptive if accessing fire for free. Individuals in a group intent on accessing fire amiably from other groups may have had to inhibit any inclination to act aggressively toward potential donors. Seeking mates or begging for food may also have been inappropriate in this context, but we cannot know. It may have been difficult for individuals who had been eating raw food to resist begging for a strip of cooked meat or some roasted vegetables. Whatever the case, any behaviour that might have upset potential donors was best inhibited. Interactions between primate groups, including humans, can be tense. Inhibiting any desire or tendency to act aggressively was probably the initial step before any kind of agreeable negotiations between groups could have taken place.

8.2.5 Summary

I have identified intrinsic and extrinsic stimuli that would have motivated early humans to seek proximate rewards and that sometimes would have conflicted with fire related tasks. These are summarised below. In most contexts, responding to these motives was adaptive and offered individuals immediate rewards. At times though, responding to these proximate needs or desires could have compromised the successful completion of a fire related task. This was because the motivation to undertake or continue a fire related task a) often coincided with competing motivations, b) does not usually offer
an immediate reward and c) is difficult to regulate using only proximate cues and needs. Some fire related tasks require attention that was extended in time and space and resilient to interference and distractions, such as accessing fire, gathering fuel and transporting fire.

<table>
<thead>
<tr>
<th>Proximate Motive</th>
<th>Adaptive Function</th>
<th>Proximate Reward</th>
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<tbody>
<tr>
<td>Thirst</td>
<td>Drink</td>
<td>Satiation</td>
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<tr>
<td>Hunger</td>
<td>Eat</td>
<td>Satiation</td>
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<tr>
<td>Sexual Desire</td>
<td>Reproduce</td>
<td>Pleasure / Satiation</td>
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<td>Available Food</td>
<td>Eat</td>
<td>Pleasure / Satiation</td>
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<tr>
<td>Available Mates</td>
<td>Reproduce</td>
<td>Pleasure</td>
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<tr>
<td>Grooming Opportunity</td>
<td>Maintain Group Cohesion</td>
<td>Pleasure / Enjoyment /</td>
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<td>with regular partner</td>
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<td>Stress Relief</td>
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<tr>
<td>Grooming Opportunity</td>
<td>Improve Access to Resources / Avoid Intimidation</td>
<td>Pleasure / Stress Relief</td>
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<td>with new partner</td>
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<tr>
<td>Fatigue</td>
<td>Induces Rest</td>
<td>Recuperate / Repair</td>
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<tr>
<td>Make a Tool</td>
<td>Improves Access to Resources / Decreases Energy Demands</td>
<td>Access a Resource</td>
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*Table 6 Proximate Stimuli that could have Conflicted with Fire Related Tasks*

In ideal conditions early humans may have been able to avoid gathering fuel on an empty stomach. However, in difficult or extreme conditions, the adaptive value of fire was at a premium. If the choice were between going hungry and the fire going out, the adaptive choice would be to keep the fire burning. This is because at critical times more individuals were likely to survive if the fire did not go out.

Fire related tasks involved attending to and interrupting ongoing tasks that were directed toward future goals. This implies future directed self-regulation from which we can infer executive functions, such as extended working memory, episodic memory and detached representation. Without the capacity to inhibit responses to proximate motives and delay gratification early humans would often have found it difficult to initiate and complete fire
related tasks. This would have resulted in individuals frequently being without fire and increased fire keeping costs due to decreased efficiency. Fire users who could inhibit responses would have been better able to ensure continued access to fire and greatly reduced fire keeping costs. Given that the benefits of fire are adaptive, it follows that individuals who could inhibit responses would have been at an advantage over those that could not.

There is no compelling evidence that non-human animals delay gratification or need executive control to inhibit responses (Stevens & Hauser 2004: 62). Other animals can inhibit responses based on information that is available to them from the present environmental context. However, when the choice is between proximate and remote goals, future directed self-regulation is required.

8.3 Anticipatory Planning

Anticipatory planning also provides good evidence for executive functions, such as extended working memory, episodic memory and detached representations. In this section I argue that anticipatory planning would have been required or adaptive when provisioning fire, transporting fire and accessing fire. I will argue that some fire related activities meet the behavioural criteria for planning, in that they involved preparing in advance for a future need. I will also consider the consequences of not planning ahead. I then reiterate and extend on my response to the objection that fire related tasks can be explained in terms of proximate motives.

8.3.1 Gathering Fuel

Gathering fuel meets the criteria for forethought. Individuals gathered fuel to satisfy a need that they would experience later in the day, or even the next day, such as a need to cook, be warm or prevent the fire from going out. Unless other mechanisms can explain gathering fuel in advance or fuel never needed to be gathered in advance, it is reasonable to infer that thinking about the future benefit motivated fuel gathering.
As discussed above, humans who did not anticipate running out of fuel would have been unlikely to do anything about it until their fuel supplies were gone or the fire was dying. Intentionally controlling when fuel supplies ran out presumes that individuals could anticipate that fuel would run out. If fire users did not anticipate running out of fuel and did not intentionally control when they would run out of fuel, then they could have run out unexpectedly at any time.

There were two ways that early human fire users could have run out of fuel. They may have exhausted supplies they had already gathered or they could have exhausted locally available fuel resources. If fire users did not gather enough fuel during the day to keep their fires going throughout the night, then the chance a fire will go out greatly increased. As local fuel loads become depleted the cost of gathering fuel and the time it takes to find sufficient supplies increases. This increases the chance that not enough fuel will be found before the fire goes out or before dusk. If local fuel becomes exhausted, then the fire will go out unless the fire is moved or fuel brought in from remote locations. Fire users who consistently found themselves in these situations would have found fire keeping difficult and were more likely to lose fire at critical times. From this it is reasonable to assume that successful fire users monitored the depletion of gathered supplies and of local fuel loads in anticipation of future needs (Ronen 1998: 445). Anticipating that fuel would run out and when it would run out were arguably critical cognitive abilities for an obligate fire user.

As with inhibiting responses, I am not suggesting fire users always had to anticipate needing fuel in advance. However, if they were unable to do this they would often have encountered situations that compromised their ability to sustain a fire. Individuals who could anticipate needs were better placed to keep the fire going than those who could not. This would have placed individuals who could anticipate future needs at an advantage over those who could not because the former were more likely to enjoy the continued benefits of fire and use fire more efficiently.
The consequences of not anticipating that gathered fuel would run out were that the fire went out, or that some individuals tried to sustain the fire while others gathered more substantial supplies. Given that fire users would quickly use up all the proximate combustible material, with higher quality fuel becoming increasingly remote (Ofek 2001: 157), always waiting until the last minute, would have been a risky. Failing to anticipate that fuel supplies would run out was a problem for Middle Pleistocene humans if fuel ran out at times when sufficient provisions were difficult or impossible to gather, in particular at night.

Running out of fuel would have been a problem if fuel loads were depleted or fuel was remote. As supplies became depleted and more remote the time and energy required finding sufficient fuel increases. Eventually, the time it took to gather sufficient supplies would exceed the time it takes for the fire to go out, or dusk to arrive. Once this situation arose saving the fire would have been difficult and sometimes impossible. The best way to avoid contingencies that would have hindered or prevented sufficient fuel supplies from being gathered is to do something about them before they occur.

Knowing that fuel runs out would not have been sufficient in itself to motivate fuel gathering. Fire users sometimes had to remember and act on this knowledge prior to fuel running out. This probably would have required emotionally affective detached representations to provide the motivation to gather fuel (Boyer 2008: 219-220). In the case of gathered supplies, fire users had a visual reminder that fuel was running out – the decreasing size of the gathered pile of fuel. This could have prompted knowledge that fuel runs out and so facilitated remembering to take action in advance. Fire users who ran out of supplies usually would have had some time before the fire itself went out, unless this happened in heavy rain. A large fire may smoulder for days, while a small fire may go out in a few hours.

Of greater consequence for fire users was not anticipating that sooner or later fuel loads become depleted. If they did not anticipate this situation, and take steps to avoid it, they would often have run out of fuel. In open
grasslands or open woodlands this would have occurred quicker than in a forest. In this situation a last minute scramble for fuel may not have worked because all the proximate fuel would have been consumed. Fire users who did not move before proximate fuel loads ran out, or stockpile fuel supplies, would often have run out of fuel. If early humans always relocated before fuel became an issue, they need not anticipate local fuel loads becoming exhausted. However, some Middle Pleistocene humans evidently spent long durations at the same location and managed to keep their fires going (Gamble et al. 2011: 123, Gowlett 2006: 304, Schiegl et al. 1996 *passim*). Evidence from the Late Pleistocene Neanderthal site at Kebara Cave in Israel suggests these people managed to keep a fire going all year round at the one location (Bernal & Goldberg 2008: 109, Lev et al. 2005: 480).

If accessible fuel was always close by and abundant, fire users need not have worried about fuel loads running out. However, this was unlikely given the environments fire users lived in (Elton 2008: 386-387), and that fuel loads nearby a fire will quickly become depleted (Ofek 2001: 157). The consequences of running out of local fuel are straightforward: the fire goes out and the group needs to access it again. To avoid this, fuel had to be brought in from remote locations or the fire moved before fuel ran out.

Fire users who could plan their day, as against simply responding to needs as they presented themselves, would have a better chance of keeping their fire going. Such people could have organized food searches, so as not to conflict with fuel searches, and conducted the latter at more convenient times to avoid running out at a critical time and to reduce fuel gathering costs (Gowlett 2006: 306). Alternatively, members of a group could divide their labour and gather fuel and food at the same time, which implies complex social cognition as argued in Chapter Nine. Scheduling activities, or dividing the group’s labour, would have been particularly adaptive at times when fuel and food were scarce, when available gathering and foraging time was

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30 Individuals may have carried fuel and food at the same time, thereby avoiding the need to stagger activities. However, this would have been inefficient if food and fuel were not close to each other and presumes individuals could trust each other to share resources.
constrained for whatever reason, or if fuel and food were not close to each other. If Middle Pleistocene fire users stockpiled fuel, then clearly they could anticipate and plan for the future. I would suggest that stockpiling fuel stands as an example of group contingency planning, which implies enhanced executive control (Coolidge & Wynn 2007: 82).

8.3.2 Protecting Fire

Protecting an exposed fire from rain would have been difficult without advanced preparation, such as ensuring a natural shelter was available or that the materials to build a shelter were at hand. If early humans made shelters for other reasons or lived in huts this may not have been an issue, but we cannot be sure if Middle Pleistocene humans constructed shelters or huts (Nobel & Davidson 1996: 207). There is some evidence of living structures from the Middle Pleistocene site at Bilzingsleben (Mania & Mania 2005: 101), but little else from this early period. However, humans living in cold environments, with temperatures dropping below zero, would have required natural or constructed windbreaks to guard against the debilitating effects of wind chill (Gillian 2007: 106).

Fire users living in the open that anticipated rain and took preventative measures in advance would be better able to keep a fire burning than those who could not. This means anticipators were more likely to have had continual access to fire’s benefits, and would have had to access fire less often. Many fire using groups kept their fires in caves (Rolland 2004: 257). Although fire users may have kept fires in caves to prevent extinguishment (Rolland 2004: 257, Ofek 2001: 164-165, James [Lewis] 1989: 15), we cannot be sure this was their intention. If fire users kept fires in caves to prevent them from going out, then they were engaging in group contingency planning, which clearly indicates they could plan ahead.

8.3.3 Accessing Fire

If fire users had to access fire by force or stealth, being able to plan ahead would have been adaptive. Overt or covert raids probably required prearranging strategies, escape routes and the different roles individuals
would play to ensure regular success. Raids may also have involved prearranging where any individuals not directly involved in the raid would meet later on. Anticipatory planning would have been adaptive if fire was exchanged for some other item because suitable exchange items would need to be arranged in advance. If individuals or a group had to travel many days to access fire, then they may have made advanced preparations. While we cannot know if Middle Pleistocene fire users would have accessed fire in these ways, or regularly undertook long journeys to access fire, it is reasonable to think planning would have been highly adaptive if fire users had to access fire from another group.

8.3.4 Objections

As with inhibiting responses and delaying gratification, it could be objected that gathering fuel, protecting fire or accessing fire were governed by proximate stimulus-response associations that triggered automated behavioural routines. I suggest that this was unlikely because direct stimulus-response associations would not always have sufficed to motivate fire related tasks, as argued above, and for the reasons offered below. Routine procedures follow relatively set sequences of actions and are marked by relatively unambiguous start and endpoints. They are closely tied to the desired outcome of the procedure, which is relatively unambiguous. Needs or environmental cues trigger a learned routine that follows a predictable and invariable sequence of actions or behaviours. Once the goal is realised, the routine ends until a need arises to enact it again. Fire related tasks would not always have been conducted in this way for three reasons.

First, as Ronen has pointed out (1998: 443), provisioning a fire involved continual interruptions and ‘breaks’, with no clear beginning or end to signal that the goal had been achieved. Provisioning would not always have been closely related to any particular or immediate need. This makes fire use more difficult to regulate in terms of cognition, because it involved representing and communicating displaced information.
Second, fire related tasks require a degree of flexibility not usually associated with automatic routines. Of course, fire users would have often conducted fuel gathering and fire tending routinely. However, these tasks had to be coordinated with other behaviours, and adjusted to varying environmental and social conditions that could have changed suddenly. The weather, fuel loads, available time and individual needs could have changed daily. Routines that may have worked most of the time would not work all of the time. For example, provisioning strategies that worked for most of the year might not have worked in snow or during monsoons. Inflexible routine behaviours that do not tax working memory could well have been maladaptive if they prevented individuals from adjusting to changes in their physical and social environments. In particular, the following conditions could have changed from day to day and week to week: the availability of gatherers, fuel availability, quality and abundance, mobility patterns, habitat and climate, seasonal change and the availability of ignition sources in relation to the frequency of contact with other groups.

Third, we need to consider fire use in terms of behavioural complexity, not as an unrelated set of procedures. I am assuming that when Coolidge and Wynn refer to fire use as a “mundane activity” (2007: 81), they are referring to gathering fuel and tending the fire, not fire use as a behavioural complex, although this is not made clear. Not all fire related tasks are mundane for the simple reason that some were probably conducted only occasionally. If we accept that fire use was governed by automated or associative procedural routines, then we need to accept that fire users acquired and performed a variety of fire related routines without much cognitive effort. I suggest that to use fire effectively the following routines would have been required:

- The access fire routine, which could have involved fire making routines
- The transport fire routine
- The establish fire routine
- The gather fuel routine
- The monitor and tend fire routine
- The cooking routine
- A range of fire protection routines to suit different environments and climates.

No other evident domain of Middle Pleistocene human behaviour was similarly complex. Fire use would have increased behavioural complexity because fire users still needed to forage, make tools, and socialize. Fire use increased the cognitive load for early humans because they had to know how and remember to do more things, and coordinate fire related activates with other behaviours. Many fire related tasks would have involved integrating different behaviours to achieve the intended result. For example, moving a fire from one location to another could have involved carrying the fire, ensuring fuel and kindling arrived with the fire and establishing a new fire. The advantage of enhanced executive control in human evolution was that it fostered minds that could do more things at the same time (Barnard 2010: 50). Fire use introduced behavioural complexity that would have selected for minds capable of processing more complex kinds of information, because fire users who could do this better were at a reproductive advantage over others. In short, fire use greatly increased the cognitive load relative to humans or other animals that are not fire users.

The objection that fire related tasks were governed by automatic stimulus-response associations, and therefore did not require planning is not compelling for several reasons.

1. Fire related tasks would not always have provided the feedback required to establish conditioned associations.
2. Fire related task often have no clearly demarcated start and end points related to a proximate need and a desired goal respectively.
3. Fire related tasks would not always have followed a relatively inflexible or predetermined sequence of events. Individuals were likely to gather fuel, cook then tend the fire one day; then tend the fire, gather fuel and cook the next day.
4. Fire related tasks would often have been interrupted, thereby breaking up any procedural sequence of events.
Unlike other provisioning systems, fuel gathering and tending a fire were often detached from immediate motives and goals (Ronen 1998: 443). This makes fire using different from gathering food and making a stone tool, and less amenable to sequential procedures and automated behavioural routines. Hallos argues (2005: 160, 175) that evidence from four Acheulean sites shows that Middle Pleistocene humans could interrupt and return to a tool making routine. It is also reasonable to think transporting and accessing fire could have involved interruptions.

Fire related tasks required a degree of behavioural flexibility, not usually associated with automated routines, to cope with fluctuating conditions. Individuals can usually enact foraging routines or tool making when they need to. However, fire use sometimes involved acting without any proximate motivation. Individuals who only acted in response to proximate needs would often have found fire keeping difficult or impossible. Also individuals rely on others to do things that they cannot and to share the workload with them. This means deciding who would enact the routine, enacting the routine if others did not, or not enacting the routine if you were not required to. Changing conditions also affect fire related tasks to a greater degree. Making a tool in winter or summer is much the same, whereas gathering wood in summer can be very different from doing so in winter. For these reasons, fire use was probably better suited to flexible, not routine, behaviours under the governance of a central executive. Fire users must remember more things, coordinate more activities at the same time, and consider future situations and contingencies that earlier humans and other animals need not consider.

Fire users who could plan ahead were more likely to succeed at fire related tasks and use fire more efficiently than individuals that could not. Fire users who could not anticipate the many contingencies associated with controlled fire use would often have found it more difficult to effectively and efficiently complete fire related tasks. Significantly, to gather sufficient supplies of fuel, fire users had to consider future situations removed from them by hours and extending into tomorrow. They may have even had to
consider days or weeks in advance if fire was to be transported a long way, when accessing fire from others, or if fuel was being stockpiled. This degree of temporal depth in planning requires foresight that is not evident in other animals, nor required for other evident Middle Pleistocene human behaviours.

8.4 Summary and Conclusion

Fire related tasks would sometimes have conflicted with more immediate opportunities to secure desired rewards. Individuals who could not inhibit responses and delay gratification would have found it more difficult to initiate or complete required fire related tasks. This would have compromised their ability to sustain a fire. Always waiting until the last minute or for some immediate need to motivate fire related tasks would have been a risky and inefficient strategy that would have greatly increased the chance of the fire going out, and reduced efficiency.

Fire users who could not anticipate future needs and prepare for them in advance would have found fire keeping much more difficult than those who could. Fire users who could not plan ahead would not have prepared for contingencies, such as rain, running out of fuel at night or depleting local fuel loads were far more likely to lose their fire than those that could. Fire users who planned ahead when accessing fire or transporting fire were also far more likely to succeed than those who could not.

Inhibiting responses, delaying gratification and anticipatory planning imply future directed self-regulation involving extended working memory, episodic memories and detached representations. Thus, we can infer these executive functions from fire related tasks involved response inhibition delayed gratification and planning ahead. Objections to these claims are not compelling because proximate motives or automatic stimulus-response associations would not always have sufficed to govern fire related tasks in ways that ensured success.
Chapter Nine: Inferring Social Cognition from Fire Use.

9.1 Introduction

Fire use involved future directed group level cooperation and providing a public good. These behaviours provide good evidence for features of human social cognition, such as informational theory of mind, collective intentionality and intersubjective communication. Following my approach in Chapter Eight, I will argue that some fire related tasks meet the behavioural criteria for these aspects of human social cognition. I conclude that individuals who cooperated and communicated in humanlike ways would have been more successful and more efficient at keeping fire than individuals who did not.

I begin by arguing that accessing, transporting, provisioning and using fire involved human modes of cooperation, and reject possible objections. I then focus on the social implications of domestic fire as a public good. The inherently social nature of fire use (Ronen 1998: 443-444) and the significance of fire as a public good (Ofek 2001: 159) has been largely ignored by those interested in the evolution of human cooperation, cognition and sociality. I then propose that fire related cooperation required delayed reciprocity, policing and punishment that imply aspects of human social cognition. I suggest that as a general rule, the chance of succeeding at any fire related task increases relative to increasing number of cooperators. This has implications for both the evolution of fire use and for the evolution of human cooperation in general.

9.2 Accessing Fire

I am assuming that fire users without fire were strongly motivated to regain it by any means available. I am also assuming that fire users could not make fire and that natural fires were not usually an option for most Middle Pleistocene fire seekers. This is not to say individuals in need of a flame would not have exploited natural fires if they could. However, the most reliable source of fire in a population of early human fire users would probably have been domestic fires.
Fire seekers could have accessed fire from other groups by force, stealth, free access or through exchange as discussed in Chapters Five and Six. All these options would have required some degree of cooperation between individuals from the same group or with individuals from another group. An individual may have been able to access fire using force or stealth, as discussed above in Chapter Eight. However, their chance of success would have been greatly reduced relative to several cooperating individuals.

Individuals intent on accessing fire from another group had to decide who would try and access the fire prior to, or when, one became available. Those who chose, or were chosen, to access fire then moved toward the target fire. They may have known what strategy they intended to use, or decided contingently depending on their situation and the attitude of those with fire. For example, if those with fire were hostile and ready to defend their fire, then the only options may have been force, stealth or abandoning the attempt. If not everyone from the fire seeking group was actively involved in trying to regain fire, for example the young, the old or the infirm, then individuals may have had to prearrange where to meet up later on.

9.2.1 Accessing Fire by Force or Stealth

The risk of injury or death increased if fire seekers tried to access fire by force or stealth from hostile groups. Experienced individuals would probably have been aware of the potential for risk and novices would soon realize this potential once they were engaged in the activity. This would have increased any aversion associated with these behaviours, thereby increasing the need to inhibit fearful responses and monitor those not helping out.

Accessing fire by force may have involved intimidating or fighting with others. This could have worked if fire seekers were numerically superior to fire defenders. However, the chance of success decreases if opposing groups were roughly equal in number. A few fire seekers would struggle to access fire from a numerically superior group of committed fire defenders. One strong individual may have been able to access fire from a numerically small group of weak individuals. However, exceptionally strong individuals
and relatively small groups of weak individuals would not have been the norm. This also implies complex modes of cooperation involving indirect and delayed reciprocity between the hypothetically strong individual and the beneficiaries of their actions, as discussed below in relation to a lone fire thief.

An alternative might have been to divert the attention of defenders while fellow cooperators tried to grab and make off with a burning stick. Similarly, trying to access fire by stealth may have involved creating a diversion to distract the attention of those with fire so as others could make off with a burning stick. The key difference between this strategy and using force is that complimentary roles would need to be understood in advance. Accessing fire in these ways would have involved several individuals cooperating with others to secure a mutually beneficial future reward, willingness to incur injury in pursuit of a shared goal and maybe adopting complimentary roles, such as distracter or fighter and fire grabber. Of course, fire grabbers may also have had to fight.

Another alternative would have been to wait in hiding for a chance to steal fire. An individual working alone could have accessed fire this way. However, this implies patience and focused attention over extended indeterminate durations, and a degree of advanced preparation that implies the executive functions discussed in Chapter Eight. Another problem for an individual fire thief is escaping with fire. Fire thieves may need to get away quickly from a hostile group to reduce the risk of being detected or caught, but they cannot let the fire go out. This would be difficult for an individual working alone. They would need to make advanced preparations, implying executive control, or they may have needed help transporting the fire. We do not know how often groups would have left fires unattended, if at all, how often they relocated or how heavily they slept. However, a fire thief may sometimes have had to wait a long time, and would have required others to provide food or take over the task. Otherwise, they may need to abandon the task to forage for food.
An individual accessing fire still implies complex social cognition. Members of a group without fire trust that an individual fire thief will succeed and return with fire, while the thief cooperates by providing everyone with fire at considerable personal risk and effort. This implies a division of labour or delayed reciprocity whereby others rewarded fire thieves in some way. The alternative is the kind of self-sacrifice usually associated with group ideals, moral values or establishing a reputation, which imply complex cultural values and belief systems.

The kind of cooperation required to access fire in these ways is cognitively demanding for the following reasons. First, the goal to establish a fire, cook or be warm will not be realized until a future point in time. Second, cooperators would require shared representations of the future goal. Third, individuals needed to understand each other’s intentions and roles, and communicate information about the intended strategy. Fourth, cooperation may have involved considerable personal effort and potential risks. This complexity makes accessing fire by force or stealth different from the spontaneous cooperation required by social hunters, or for mutual defense.

Using force or stealth is perhaps the least cognitively demanding way to access fire. Once a target fire was identified, we have a proximate motivation to act, albeit toward the sub-goal of regaining fire, and not the ultimate goal of establishing a fire or using fire. Given that individuals know others in the group share their desire to regain fire, the intention to access fire would have been relatively clear to potential thieves once fire had been identified. The actions of individuals in a fire-seeking group are also mostly apparent to others in the group, so fire seekers can see what others are doing and adjust their behavior accordingly, limiting the need to plan a strategy in advance. Of course, they may have had to hide from members of the other group, thereby concealing themselves from fellow fire seekers.

Fire seekers who tried to access fire by force or stealth had a much greater chance of success if they cooperated and planned ahead. Given the potential costs involved, using force or stealth would have been less effective
and efficient than free access to fire or exchanging fire for something else. Fire defenders in particular seem to have little to gain and a lot to lose, unless those wanting fire also intended to put out the defenders’ fire or take other resources as well. They may have had reasons that we cannot know, such as territorial disputes (Goudsblom 1986: 522), thus hostile exchanges cannot be ruled out. Nevertheless, we have to consider why individuals would defend a fire if it was not adaptive and could have been avoided. If there were no territorial advantage or access to other resources at stake, then fire users with fire would have no reason to risk violence from fire seekers.

9.2.2 Free Access and Exchange

Individuals with fire could have allowed those in need of fire to access their fire unhindered. Under some conditions free access would not have been adaptive because of the free rider problem (Ofek 2001: 160). If access was relatively cost free, some individuals may be encouraged to free ride, and this may put them at an advantage over diligent fire keepers. The problem is if those incurring the cost of maintenance are out competed, then everyone might miss out. If free access was not frequent, not unidirectional and required that fire seekers had to travel some distance, it could have been a viable means of accessing fire.31 If access involved travel costs and was not frequent, then diligent fire keepers may not have been at a disadvantage relative to those in frequent need of access.

Free access would have been highly adaptive because groups who helped each other probably spent less time without fire and would not have incurred the costs associated with more hostile interactions. Those involved in conflicts over fire would arguably have found fire harder to access, been without it for longer durations and could have died trying to get it. In marginal environments a network of fire lenders may have been required to ensure fire was not lost at critical times (Gowlett 2006: 306). Although speculative, this kind of interaction between groups would have had the

31 Reciprocal exchange, along the lines of ‘I give you fire then you give me fire’ was unlikely for the reasons discussed in section 6.2.3 above. However, this strategy could have been relevant in communities of proximate groups.
potential to establish obligations between groups, social bonds, and exchange networks. This kind of cooperation between individuals from different groups would have been highly adaptive in a population of obligate fire users.

Intragroup cooperation of this kind is a uniquely human behaviour. It would have required a means of requesting fire, communicating that intentions were peaceful and that a request had been accepted. Individuals from different groups had to understand each others intentions and communicate information about these intentions. For example, individual ‘B’ knows that individual ‘A’ wants fire, and individual ‘A’ knows that individual ‘B’ knows this and hopes or knows that individual ‘B’ intends to help out.

Those with fire could have exchanged fire for some other good or service, rather than just allowing others access to their fire. If hostile exchanges were too costly, and free riding a problem, then exchange may have been the only viable way to access fire from other groups (Ofek 2001: 160). Exchange solves the free rider problem because the provider is not disadvantaged, the temporal delay problem of reciprocal exchanges, and the risk problem of hostile interactions. Offering something like food or a tool may also have been a good way to placate potentially hostile individuals and gain access to fire without violence.

Again this would have been an adaptive win-win situation for all concerned. Those without fire gain a great deal for little cost and risk, while those with fire gain a little with no cost or risk. While exchange would have been adaptive, it was probably not necessary in most contexts, as free access, and force or stealth would have sufficed. That said, fire use established selective contexts in which goodwill towards other groups or incipient forms of exchange would have been adaptive (Ofek 2001: 160), and we can imagine probable situations, such as surviving in marginal environments, in which it may have been required. For example, keeping fire during cold Northern European or Asian winters may have required reliable networks of free access or mercantile exchange (Gowlett 2006: 307).
9.2.3 Summary

We cannot rule out that Middle Pleistocene fire users could make fire or never let their fires go out. However, fire making and indefinite fire keeping also imply complex cooperation and cognition. Fire making implies high fidelity cultural transmission, divisions of labour, group contingency planning and complex technological reasoning. Keeping a fire going indefinitely would have increased the demand for intergroup cooperation, and implies a failsafe means of protection and group contingency planning. Thus, the cognitive demands of fire use are potentially increased under these conditions, thereby strengthening, not weakening my argument.

Accessing fire from a domestic source very likely required intergroup or intragroup cooperation. Both kinds of cooperation imply acting to secure a future reward, sharing intentions at the group level, understanding the different intentions of others, and communicating information about intentions, goals, strategies and roles. If exchange was involved, then the value of exchange items had to be negotiated, which implies sophisticated communication. Accessing fire from other groups also implies the executive functions required for future directed self-regulation, overcoming fear and suppressing self-interested inclinations that undermined the cooperative effort. Accessing fire from others implies trusting members of one’s own group or individuals from other groups. From this kind of cooperation we can infer collective intentionality, an informational theory of mind and an intersubjective means of communication. While it is not certain that individuals cooperated in these ways to access fire, fire users who did would have been more likely to succeed than those who did not.

9.3 Transporting Fire

Transporting fire implies cooperation for two reasons. First, individuals who cooperated were far more likely to succeed. Second, a lone fire transporter cooperates with other members of the group by ensuring that they continue to benefit from fire. Individuals may have cooperated by helping those carrying a burning stick or a fire carrier, or one individual may have transported the fire and started a new fire without assistance.
Helping others to transport fire would have been adaptive. Helpers could have ensured dry kindling and fuel were ready when needed, provided those carrying the fire with water and food or relieved individuals of the task if they became tired or inattentive. If fire was being transported over long distances and had to be carried by individuals for several hours, then helping in these ways would have greatly improved the chance of success, and may have been required. For example, transporting fire through snow, on very hot days, in rain or through the territory of predators may have required cooperation.

One individual could have transported fire without assistance. However, this probably required preparation and concentration over extended periods of time. Preparation may have been required because a lone fire mover may need to start a fire at short notice as contingencies arose. To do this they would need to ensure dry kindling and fuel were available. An individual carrying and attending to a fire for several hours incurs considerable costs for the benefit of other group members. This could have put the individuals transporting fire at a disadvantage because those not involved could forage along the way and take advantage of other opportunities that those moving fire could not. Given that all members of the group have an interest in transporting the fire successfully, it would have been better if those incurring the cost were not disadvantaged. This implies divisions of labour involving specialization, or that those who transported the fire were compensated, implying delayed reciprocity.

If individuals worked together to transport fire, they cooperated. This kind of cooperation was directed at a future goal and may have involved adopting complimentary roles. It may also have involved more than two individuals or even all group members. It implies understanding the intentions of others, and trusting them to fulfill their roles. It implies communicating intentions, such as “I need some help”, “get some wood” and “we need to start a new fire now”. If an individual transported fire for the group, then cooperation involving delayed reciprocity is implied. For example, I might transport fire knowing that you will give me some food.
9.4 Provisioning Fire

Keeping a fire burning continually implies cooperation for two reasons. First, it would have been difficult for one or a few individuals to maintain a fire and provide for themselves without help. I am not suggesting an individual cannot keep a fire going. However, I am suggesting that for the most part spending time and energy gathering fuel and tending the fire while other individuals rested, foraged for food, groomed each other or mated was not adaptive. All else being equal, selfless fire providers eventually would not have been able to sustain both themselves and the fire. At this point everyone misses out on the benefits of fire unless others help out.

Second, in a group of fire using individuals, the lone fire provider was at a disadvantage relative to those who benefitted from their behaviour. In this situation, the fire provider was less likely to survive and reproduce than others because they had less time to forage, rest, socialize and seek mates. Thus, behavioural dispositions towards unconditional cooperation would be selected against. When the fire provider died so would the fire. From either an economic or an evolutionary perspective, unconditional cooperation by one or a few individuals in the group was probably not an option for most fire users.

Providing a domestic fire is much easier if everyone in the group cooperates. Twelve fuel gatherers spend far less time and energy than do one or two. Individuals in groups with many cooperators would have used fire more efficiently and were more likely to have regular access to the benefits of fire. This would have put them at an advantage over individuals in less cooperative groups. The cost to providers and the relative benefit to free riders increase with an increasing number of defections. If this is allowed to continue free riders will come to outnumber cooperators. Therefore, it is reasonable to think mechanisms were in place to prevent this scenario (Ofek 2001: 160). Once the number of cheaters reaches a maximum threshold provisioning fire becomes too difficult. In an economic and evolutionary sense, this would be the point at which the cost to those providing the fire becomes excessive, or when fire providers become extinct.
There are different ways fire users could have avoided these difficulties. Individuals in a group could have shared the workload evenly. Alternatively, individuals who dedicated less energy to providing the fire could have compensated those who spent more energy. Fire providers may have gathered fuel together, which would have made free riders easier to detect. However, if individuals made their contributions at different times of the day, then monitoring contributions, trust, honesty, social norms or the threat of sanctions were probably required to regulate provisioning. If resources were scarce or widely distributed groups may have had to split up to ensure fuel and foods were gathered. This is cognitively demanding because it requires knowing that remote others were gathering fuel or food, and that these resources would be shared later in the day. While this scenario is hypothetical, it represents a coordination problem that fire users were often likely to encounter.

Compensating fire providers implies an incipient division of labour. Fire users could have divided their labour to ensure fuel was gathered and the fire tended. Some individuals could have spent more time and energy than others gathering wood or tending the fire. However, it is not in an individual’s interest to provision a fire for free. Thus, mechanisms that compensated fire providers would have been required for this strategy to evolve. A division of labour may have involved either delayed reciprocity, even if only for a few hours, or food sharing. For example, one individual could gather fuel and tend the fire for a few hours while others foraged in return for a share of the food gathered or some other reward. It would have required identifying who was supposed to be doing what, and keeping track of who owes what to whom. This implies not only knowing who does what, but trusting that other members of the group will keep their end of the bargain. While we cannot know if fire users divided their labour in this way, in difficult conditions individuals may have had to maintain the fire while others foraged for food.

Fire users could have cooperated to improve efficiency. Collaborative fuel gatherers can maximize returns and minimize energy expenditure. Skymes points out (2008: 21-25) that two hunters collaborating can bring
down a stag, but can only bag a hare each with the same investment when working alone. One stag is worth much more than two hares. Similarly, two fuel gatherers can carry a large dead branch that may sustain a fire for days whereas two armfuls of wood may only last a few hours. Unlike the collaboration of social carnivores, the goal is in the future if fire users adopted this strategy. While we cannot know that fire users collaborated in this way, fire users who did so when the opportunity arose would have had an advantage over those who did not. Thus, fire use established an evolutionary context in which individuals who cooperated in this way would have been at an advantage over fire users that did not.

These provisioning strategies would have required practical social knowledge. If individuals ‘A’ and ‘B’ did not gather fuel, it is better to know that individuals ‘C’ and ‘D’ would. If individuals gathered fuel but no food, they would have needed to know others would provide them with food. If individuals left the fire untended they may have expected that others would tend it in their absence. This kind of social information facilitates human cooperative behaviours, and implies trust, social obligations or norms, collective intentions, self-identity and an informational theory of mind. These are required to know that I am doing this and you are doing that and to keep these intentions distinct (Knoblich & Sebanz 2008: 2021), and to understand that we intend to keep the fire burning (Toumela 2007: 5).

Whichever way early humans provisioned their fires, they probably cooperated in humanlike ways. If they worked together, contributions needed to be roughly equal between group members. If they divided their labour, individuals that dedicated more time and effort to provisioning the fire needed to be compensated by those that did not. As with accessing and transporting fire, social roles and obligations directed at future rewards need to be understood. Group level cooperation would have been adaptive, if not required, to gather fuel and tend fires. Individuals who cooperated in these ways would have increased their efficiency and reduced the risk of losing fire relative to fire users who did not.
9.5 Cooking and Cooperation

In primate societies, stronger individuals tend to take food from weaker members of the group if they can. This is not such a problem if food is consumed as it is procured. However, this can be a problem if the consumption of food is delayed (Sterelny 2005: 137). In the context of central placed foraging, with food being brought to and cooked at a central location, delayed consumption provided stronger individuals with opportunities to steal food from others. Strong individuals could wait for others to bring food back to the fire and take it, or roam from fire to fire stealing cooked or raw food (Wrangham 2009: 158-159).

Food stealing is not adaptive in a fire using society. While bullying and food theft are common in many primate and human societies, fire use imposed limits on the degree of food stealing that could be tolerated. Individuals who regularly lost food to others, or had to avoid food stealers and eat raw food, cannot regularly enjoy the benefits cooking provides. Individuals who were often exploited in this way would be less inclined to gather fuel for a fire they cannot always use. They would also have less time and energy to gather fuel because they would have to forage for more food to replace what had been taken, and eat raw food more often. This could have greatly increased the provisioning demands for food stealers, who would need to make up shortfalls induced by their behavior. It is not in a free riders interest to steal food if it increases their fire provisioning costs, particularly if they were also trying to avoid the cost of fuel gathering.

Thus, it is reasonable to think individuals who were inclined to steal food had to curtail this behavior to some degree or steal food selectively from particular individuals so as not to discourage those helping to provide the fire. Cooperating, with others in this way was important, lest food stealers one day find themselves sitting by a cold pile of ash with no one to steal food from. Alternatively, it would be in the interest of those being exploited or bullied to gang up on uncooperative thieves and either discourage them or exclude them from the fire altogether. As discussed in section 8.2.3 above, cooperating in these distinctively human ways is cognitively demanding.
9.6 Domestic Fire as a Public Good

A domestic fire is a public good in an economic sense (Ofek 2001: 159). The cost of excluding free riders is high and one individual’s consumption of the good does not reduce the supply available to others (Ofek 2001: 146). Individuals are better off free riding so long as others continue to supply the good. Public goods are invariably subject to free riding without incentives that encourage cooperation, such as reciprocity or the threat of sanctions (Shinada & Yamagishi 2007: 330, Kurzban & Houser 2005: 1803, Fehr & Gächter 2000: 980, Hawkes 1993: 347). Without these kinds of incentives public goods will be undersupplied (Hawkes 1993: 347). Free riding undermines all cooperative efforts (Kappeler & van Schaik 2006: 14-16). Gamble et al. identify (2011: 118) free riding as a major evolutionary driver of human social cognition.

Modern human societies use a range of culturally acquired mechanisms from shame to state sanctioned incarceration to encourage cooperation. There is no evidence for mechanisms of this kind in other primate societies (Fehr & Fischbacher 2004: 189), and no evidence for public goods. Non-human primates are good at securing selfish benefits, but are poor cooperators (Tomasello 2009: 13-55, Hirata 2009: 3). Evidence suggests that around 63% of individuals are conditional cooperators who cooperate if others also cooperate. Cooperators who cooperate regardless of what others do and free riders that avoid cooperating if they can, make up the other 37% (Kurzban & Houser 2005: 1803). However, almost total cooperation can be attained if free riders face a credible threat of punishment (Fehr & Gächter 2000: 980). Without punishment contributions to public goods consistently decline in experimental and real life situations (Kurzban & Houser 2005: 1803, Fehr & Gächter 2000: 980). Based on the evidence from contemporary primate and human societies we have no reason to think Middle Pleistocene humans were more cooperative than people today (Ofek 2001: 159). Thus, it is safe to assume that Middle Pleistocene fire users had to deal with the problem of free riding.
Free riding would have had negative short and long term consequences for fire users. In the short term, it increases the relative cost to fire providers, thereby increasing the chance that the fire will not be provided. In the long term, the inclusive fitness of individuals providing the fire is reduced relative to free riders. If free riders were at an advantage over the individuals who provided the good, fire use would not have been a stable evolutionary adaptation and probably would not have evolved. Fire use did evolve, which implies that forces came into play that encouraged cooperation and discouraged free riding (Ofek 2001: 160).

In a group of fire users the cost to providers increases with each additional defection. If an individual needed to spend an average of two hours a day providing for an optimal sized fire, then twelve cooperators would spend an average of ten minutes a day. However, one or two fire providers would have to dedicate one or two hours a day. Once more than 50% of individuals defect, the cost of providing the fire begins to increase exponentially with each further defection.

When foraging and fire keeping costs were above average, it would have been very difficult for one or a few individuals to sustain the fire and themselves. Even if free riding were the norm, at critical times free riders would have had to contribute in some way to keep a fire burning throughout the year. Ironically, free riders would have had to cooperate sometimes to ensure that fire providers could maintain the public good that allowed them to free ride in the first place. However, if free riding was the norm in fire using populations it is unlikely controlled fire use would have evolved.

In a population of fire users the inclusive fitness of free riders is greater than that of cooperators so long as the latter continue to provide the fire. Free riders benefit from the cooperative behaviours of their social partners without paying any cost (West et al. 2010: 5). In a population or group in which everyone cooperates the introduction of just one cheat through mutation or migration could lead to no cooperators within a few generations (West et al. 2010: 5). Given free riders will leave more offspring than fire
providers, and assuming these offspring are also free riders, cheaters will outcompete fire providers and there will be no one left to keep the fires burning (Ofek 2001: 160). The economic and evolutionary viability of public goods entails that providers are compensated, or that free riders are encouraged to cooperate or excluded, and these behaviours involve kinds of human cooperation that demand complex social cognition.

Fire use implies effective ways to detect and deal with free riders. From this we can infer that fire users could identify cheats and monitor the behavior of individuals through time and space. This required individuals attending to and remembering how others had behaved, communicating this kind of information to others, deciding together on a course of action, and cooperating to sanction or punish those identified as cheats. Alternatively, culturally acquired social norms could have supported a commitment to the common good. While social norms make free riders easier to detect (Sterelny 2007: 723-724), they imply high fidelity cultural transmission and a well developed intentional psychology. Because fire use was a public good, it may have depended on the human capacity to establish and enforce social norms that is evidently lacking in other apes (Kappeler & van Schaik 2006: 14-16). This has implications for the evolution of morality: a sense of right and wrong, and of how one ought to or should behave, and how my behavior affects others. “Morals are shared understanding, within a group of people, of how to live and work together” (Friedman 2008: 19)

Delayed reciprocity, policing and punishment support cooperation directed at common goods in human societies (West et al. 2010: 6). Culturally transmitted concepts of social value and obligation or social norms also support cooperation directed towards the ongoing production of public goods (Sterelny 2007: 723-724). These provide good evidence for collective intentionality, an informational theory of mind and high fidelity transmission of information about social obligations, prohibitions and free riders.

One objection to this argument is that domestic fire was not a public good. This may have been the case if individuals could make fire. It is easier
to exclude a free rider if the fire does not have to burn continually. Potential cheats would have to wait until a fire was made, and fire makers can put a fire out after use. Fire makers do not need to keep a fire continually burning and so would have used up less time and energy tending the fire and gathering fuel. This would have reduced the potential relative benefit to free riders. Finally, if most individuals could make fire they do not really need to free ride because it is easier just to make a fire when you need one. In a population of fire makers a domestic fire may not have been a public good. However, widespread fire making skills required complex technological knowledge and communication skills that imply more complex cognition than I am suggesting a fire user required. A fire that burns continually is available most of the time to all members of the group, and to individuals from other groups unless they are actively prevented from accessing the fire.

9.7 Fire Use and Human Cooperation

From the discussion so far it is reasonable to infer that fire use may have involved many defining features of human cooperation including; group level cooperation, high-risk cooperation, cooperation between non-kin, a willingness to punish non-cooperators, delayed reciprocity, social norms and perhaps also reputation-based reciprocity and commodity exchange. Ronen has proposed that, “Keeping and supplying the fire were group activities” (1998: 443).

Accessing, provisioning, and using fire would often have involved sharing the work or a division of labour, which imply group level cooperation. If individuals collaborated to access fire by force or stealth, or attempted to defend a fire, then they were engaging in high-risk cooperation. Sanctioning free riders and the uncooperative was probably necessary for fire use to evolve. This was potentially a risky form of cooperation if it involved physical violence and if free riders and the uncooperative were strong individuals who were likely to retaliate.

Keeping a communal fire involved cooperating with non-kin, unless all members of the group were closely related, such as parents and their
offspring; however this does not necessarily exclude grandparents. By cooperating, individuals related in these ways could improve their fitness through kin selection. It is reasonable to think Middle Pleistocene groups were not made up entirely of close kin because for viable human populations to exist, breeding individuals had to transfer from one group to another. Thus, groups could not have been comprised entirely of close kin. Evidence suggests that some Neanderthal groups were patrilocal in that the males in the group were closely related, whereas the females were not (Lalueza-Fox et al. 2011: 250). If Middle Pleistocene humans accessed fire for free or through exchange with other groups, then they were probably cooperating with non-kin.

In human societies reputation facilitates cooperation. Fire use probably involved reliance and trust, which form the foundation of reputation in modern human societies. Fire related tasks required that individuals could trust and rely on fellow cooperators and this implies reputation based cooperation. Individuals could have come to be known as more or less reliable in different fire related situations, or renowned for their expertise at a particular fire related task. Individuals may have been understood or reputed to be more or less reliable at different tasks. Conditional cooperation depends on knowing how reliable potential partners were.

Humans engage in various forms of exchange. Although we cannot know if Middle Pleistocene humans exchanged goods and services in fire related contexts, fire was the perfect medium to promote exchange (Ofek 2001: 161). Specialist fire keepers, reciprocity, intragroup exchanges and divisions of labour would all have been adaptive solutions to fire related problems.

In summary, fire use meets many of the criteria that indicate human cooperation, and established conditions in which all the features of human cooperation would have been adaptive. Individuals that never cooperated would have found keeping a fire and having regular access to fire’s benefits very difficult. Cooperation increases the efficiency and effectiveness of fire
related tasks. In many situations fire related cooperation would have been collaborative, in that it was directed at a mutual future benefit that could only be realized if individuals cooperated. Individuals could have helped each other by providing useful information about fire related tasks and cooperated by allowing others to benefit from the fire through unhindered access. If individuals allowed members from other groups to access their fire they were cooperating, most likely to avoid conflict.

Fire use established a social context in which intersubjective communication was probably required. Understanding the communicative intentions of others, ostensive signaling, predication and displacement are all implicated in fire related cooperation. These were critical prerequisites for language to have evolved. Fire use would have established a selective context in which all these features of language would have been required or adaptive. Examples include: drawing the attention of others to the location of fuel sources or the state of current fuel supplies, drawing attention to the location of a potential fire source, communicating one’s intentions to move, access or provision a fire, communicating imperatives and recruiting help. Instructing prohibitions and obligations, and communicating information about free riders would have required language-like communication. Communicating important fire related social information concerning the activities of different group members, and making group decisions would also require these linguistic capacities.

Domestic fire was a powerful, and perhaps the preeminent, cultural medium for facilitating the evolution of human cooperation and allowing it to stabilize in human populations. Fire use was a cultural behaviour that favoured group level cooperation (Soltis 2005: 222). Individuals in cooperative fire using groups were at an advantage over those in less cooperative groups because the latter were more likely to lose fire and would have used fire less efficiently. Fire use could have involved all the mechanisms that allow cooperation to evolve including kin selection, direct reciprocity, indirect reciprocity, network reciprocity and group selection (Nowak 2006:1562).
9.8 Summary and Conclusions

Fire related tasks meet the behavioural criteria that imply features of human social cognition. From this we can infer informational theory of mind, collective intentionality and a protosymbolic means of communication. Fire related cooperation involved many behaviours that make group level cooperation cognitively demanding. These include future directed group level cooperation, collaborative cooperation, complementary action involving delayed reciprocity or a division of labour, and individuals acting remotely from each other towards a common goal. The dual problems of collective action and remote rewards can be difficult even for modern humans to overcome (Bird et al. 2008: 14769). Keeping fire involved tolerance, trust and keeping track of free riders. Keeping fire probably involved conditional cooperation. This requires that social information about the behaviours of other individuals had to be regularly attended to and updated. From this we can infer a complex intentional psychology beyond that of other primates and that was not necessarily required for other early human behaviours.
Chapter Ten: Summary and Conclusions

10.1 Introduction

This chapter summarizes my argument and conclusions. I then discuss my conclusions in contrast to other characterizations of Middle Pleistocene human cognition, and present a functional model of early human cognition derived from the cognitive demands of fire use. I then discuss the significance of the thesis in terms of future directions for research and how my conclusions improve our understanding of Middle Pleistocene human cognition. Before making concluding remarks, I will acknowledge the scholars whose ideas I have developed throughout the thesis.

10.2 Summary and Conclusions of the Argument

10.2.1 Summary

The earliest clear evidence for fire use by humans dates to the beginning of the Middle Pleistocene around 790 kya. Archaeological evidence for fire use is more common by around 400 kya and widespread in Neanderthal and *Homo sapien* populations by the end of the Middle Pleistocene, around 126 kya. Evidence for brain evolution, migrations into cooler temperate regions, and the increasing use of caves by early humans support the premise that societies of competent fire users have existed since the beginning of the Middle Pleistocene. Fire use may well predate the Middle Pleistocene by more than a million years. However, on the basis of current evidence the Middle Pleistocene provides a sound empirical basis for making inferences about fire using behaviours.

From the universal properties of fire and the conditions in which Middle Pleistocene domestic fires were kept we can infer the kinds of problems fire users had to overcome. Solving these problems required that fire users behaved in ways that provide good evidence for distinctively human cognitive processes. The fact that fire users were able to solve fire related problems implies a range of human cognitive abilities. Specifically, the following inferences are reasonable given that fire users were able to solve fire related problems.
Fire users sometimes had to overcome conflicts of interest between immediate and delayed rewards, and between individual and group interests. This implies that fire users could inhibit prepotent and selfish responses, that they could delay gratification, and that they could represent information about future goals and social obligations. From this we can infer an extended working memory capacity relative to the other apes, and the ability to form detached representations.

Fire users had to attend to fire related tasks over extended periods of time. For example, transporting fire, accessing fire, tending a fire throughout the day and night, and gathering fuel for extended periods required ongoing attention. In these cases attention sometimes had to be maintained over long periods, or was required intermittently over time. Fire related tasks could have been conducted in conjunction with other activities, which implies keeping more than one goal or task simultaneously in mind. Fire related tasks would have taxed the working memory capacity of fire users in ways hunting and tool making behaviours would not have.

Fire users could not always have gathered fuel on the basis of immediate needs. Strategies based on stimulus-response associations would not have been as efficient or effective as planning ahead. Fire users who did not anticipate running out of fuel would often have run out of fuel at times when sufficient supplies could not have been gathered. This implies that fire users sometimes acted in their present to secure a future need. Most fire related tasks were directed at securing a future reward. Whenever fire users transported fire, tried to protect fire, or accessed fire they were probably acting in the present to satisfy a future need that they were not currently experiencing. We can say these activities involved foresight, because representing the future goal was often required to motivate these behaviours. From this we can infer detached representations and episodic memory.

Fire use required a degree of behavioural flexibility from which we can infer executive control over behaviour. Fire users had to contend with changing social and environmental conditions. Those who were unable to
change strategies contingently were more likely to lose fire when conditions changed. Similarly, individuals who could not shift from gathering food to gathering fuel, or from grooming to gathering fuel as the situation demanded, would have struggled to maintain a domestic fire. Behavioural flexibility implies extended working memory and executive control over behaviour.

Fire users engaged in group level cooperation directed at future rewards, which implies joint attention, mental state attribution and collective intentionality. Keeping a fire burning, accessing fire and using fire to cook required the cooperation of most, if not all, group members. Future goals and individual roles must be represented, and individuals must know that their intentions are shared and how others intend to act. Individuals had to envisage enjoying the mutual future benefit, know that others could be trusted, as well as what was expected of others and themselves. Controlled fire use implies an unprecedented belief / desire psychology incorporating three or even four levels of intentionality. For example individual ‘A’ knows that ‘B’ will help and vice versa, and both know that ‘C’ will help them both. Cooperating to solve fire related problems implies that ‘we’, not ‘I’, intend to bring about the desired state.

Fire use involved collaboration beyond the mutualism of social hunters. It required ongoing group level cooperation to bring in fuel, tend the fire and allow unhindered access to the fire. From this kind of cooperation we can infer that fire users had a concept of ‘self’ and of ‘us’. This is because sometimes group interests had to be valued over selfish interests concerning fire (Ronen 1998: 443-444). Without some notion of ‘us’ or the group, individuals would have no motivation to act in the interest of other group members. For human cooperation to occur, individuals must be able to keep self interests and group interests apart in their mind (Knoblicht & Sebanz 2008: 2021). Too many self-interested individuals would undermine social coherence and fire keeping efforts. Thus, most individuals would have had to be acting in the group interest, at least with respect to fire related tasks, for everyone to benefit.
Fire related collaboration would have required levels of trust and tolerance not required to engage in the evident hunting and tool making behaviours of Middle Pleistocene humans. This is because individuals relied on and trusted each other to not steal food or other resources from one another (Wrangham & Carmody 2010: 197), and to cooperate to secure future rewards. This implies culturally transmitted norms and obligations. This kind of cooperation may not have been required before the evolution of central placed foraging in humans, which may be directly correlated with the evolution of fire use (Rolland 2004 passim).

Because a domestic fire was a public good, fire users probably required effective ways to detect and discourage free riding. Some form of real or implied punishment was probably the only way to induce the cooperation needed to maintain a public good (Shinada & Yamagishi 2007: 330, Fehr & Gächter 2000: 980). These are cognitively demanding behaviours that imply monitoring the behaviour of individuals through space and time. Cheating had to be discouraged through enculturation or by identifying and sanctioning cheaters. This would have required knowing who had been doing what, and conveying that information to others. Sanctioning would also have involved cooperation whereby individuals incurred a cost to themselves for the good of the group. Providing a public good implies cooperators who were willing to sanction the uncooperative, or culturally acquired social values. Nothing like this exists outside of human societies, and other evident Middle Pleistocene behaviour would not necessarily have required these features of human social cognition. The structure of my argument is outlined in Appendix Four.

10.2.2 Conclusions

From fire use it is reasonable to infer the following human cognitive abilities. Fire users had an extended working memory capacity relative to other apes and earlier fireless hominids. The evidence for ape interactions with fire discussed in Appendix Five does not refute these conclusions. Fire users could represent detached information relative to their current circumstances and perceptions. They could think about the future, and plan
ahead in anticipation of contingencies. Fire users had a complex belief/desire psychology incorporating collective intentions and three to four levels of intentionality. Fire users cooperated in human-like ways involving trust, tolerance and culturally transmitted social values. Fire users required an intersubjective means of communication involving ostensive signaling, predication and displacement.

I suggest this is a conservative view of Middle Pleistocene human cognition that considers only the minimum cognitive capacities required to solve fire related problems. However, fire use could well have, and probably did, involve even more complex and cognitively demanding behaviours. For example, I have discussed the likelihood that fire use involved divisions of labour, delayed reciprocity, mercantile exchange and group contingency planning. While these kinds of behaviours may not necessarily have been required to use fire, they clearly would have been adaptive in a fire using context. In extreme or marginal environments, they were probably required behaviours. Fire use is also suggestive of higher levels of conceptual abstraction, in that fire may have come to be valued as a good in its own right, rather than as a means to an end.

Given that cognition describes the processes involved in acquiring, interpreting, representing, organizing and communicating information, I will now consider the kinds of information that make fire use a cognitively demanding behaviour. Fire users had to represent information about future rewards and situations. This was required to motivate action, make decisions about which strategy to use and to suppress any responses that interfered with ongoing fire related tasks. When gathering fuel, fire users often had to consider tomorrow’s prospects to ensure that fuel did not run out.

If fire users stockpiled, or kept fires in caves for protection, then they may have been thinking weeks, or even months, in advance. Accessing fire involved thinking many hours, or even days, ahead. Gathering fuel, transporting fire and accessing fire imply that individuals attended to the future goal. You do not need complex concepts of time, chronological devices
or linguistic concepts of tense to achieve this. However, a relatively precise sense of duration or sequences and being able to distinguish past and future representations from current situations was probably required.

Fire use implies understanding information about quantities in relation to a sense of time. This was required to make assessments about how much fuel was available in relation to their future needs. These assessments were required to ensure fuel did not run out at times when fuel could not be gathered. Again, a formal system of weights and measures would not have been required. However, fire users needed to be attentive to fuel loads and supplies, and when they might run out of them lest they run out at an inopportune time. This implies mathematical abstraction (Ronen 1998: 445). Fire users who could not anticipate running out of fuel, and who could not assess how much fuel they needed, were more likely to run out of fuel.

Fire users had to refer to social information concerning what others were doing, had done or would do. They had to understand social expectations – what was expected of them and what they could expect of others. Accessing fire, gathering fuel, using fire and transporting fire required the cooperation of most group members, even if some were not directly involved in a specific task at a specific time. At base, individuals needed to know that others would help them directly or indirectly with fire related tasks, and that they would not steal food from each other.

They also had to be able to represent and make sense of information about free riders. For example, I might know that Gronk eats bananas and then sleeps when everyone else is looking for fuel, but I know others are not aware of this. Unless we can inform each other about defectors, we cannot do anything about them. Then others may adopt Gronk’s cheating behaviours, or he may leave more offspring. As an increasing number of cheaters are maladaptive in a fire using society, fire users must have been able to inform on cheaters and organize effective strategies to prevent the behaviour.
10.3 A Functional Model of Middle Pleistocene Human Cognition

I now compare and contrast these conclusions with other models of early human cognition that have been proposed. I then present a functional model of early human cognition derived from the above conclusions. The dehumanising hypothesis, discussed in section 2.2 above is not consistent with the evidence for fire use. The cognitive demands of fire use imply that this view of Middle Pleistocene human cognition is highly inaccurate. Thus, the suggestion that Middle Pleistocene humans lacked foresight, executive control over action and a complex intentional psychology should be rejected.

On the basis of archaeological evidence Coolidge and Wynn propose that *Homo heidelbergensis* possessed the following cognitive abilities, and differed from *Homo erectus* in these respects (2009: 177):

- Spatial cognition with allocentric perception and coordination of spatial quantity and shape recognition.
- Technical cognition with longer, more hierarchically organised procedural routines.
- Shared attention required for technical learning.
- Ability to maintain two goals simultaneously (suggests a possible increase in working memory capacity).
- Attentive use of indexical signalling.

This list is conservative. Coolidge and Wynn consider only the minimum necessary cognitive competence required to engage in the foraging and tool making activities of humans living around 500 to 200 kya (2009: 177). I suggest that these abilities would not have sufficed to keep a fire going. Collective, as well as shared, intentions would have been required to coordinate group activities. Fire users would have required an increased working memory capacity to keep track of free riders, to attend to fire related tasks that were extended in time and to coordinate fire related tasks with other activities. For example, searching for fuel and food at the same time. Indexical signaling may have sufficed, given that it had a protosymbolic or intersubjective quality, and individuals inferred a great deal of meaning from the communicative context. Indexical signaling may not have sufficed to effectively communicate information about free riders and future plans.
Fire users probably required some ability to combine indexical signals into higher order meanings, derived from knowledge of intentions and expectations. For example, pointing to a dead fire and then smoke in the distance may indicate an intention to access fire, and serve as a request or demand for help. However, a lot needs to be understood in advance, including the significance of pointing, for meaningful communication of this kind to occur.

My model of Middle Pleistocene human cognition is consistent with the view that language evolution did not happen overnight, but evolved through a protolanguage phase, or perhaps several phases. We did not get from the australopiths to Cicero in one step (Donald 2001: 268). A limited corpus of conventional signs and a few rules for combining them into meaningful expressions would have sufficed. The key importance of a protolanguage is that it would have allowed for the transmission of information about displaced phenomena, and culturally specific social prohibitions and obligations.

Barnard et al. (2007) have proposed a series of increasingly complex cognitive architectures to explain the evolution of human cognition from an ancestor with ape-like cognitive abilities. Apes are said to have a cognitive architecture incorporating six integrated subsystems, whereas modern humans have a nine subsystem architecture. Homo erectus is credited with seven subsystems, whereas Homo heidelbergensis and the Neanderthals are credited with eight. The elegance of this proposal is that each architecture establishes the foundations and conditions from which the next can evolve in realistic stages (see Barnard 2010: s44, for a cladistic representation of how these architectures evolve one from the other). There is no need to invoke hopeful monsters, language genes, or cognitive revolutions to account for the emergence of our unique cognitive skills. This staged approach is also more in line with the increasing archaeological evidence of complex behaviours from the Middle Pleistocene and the fossil evidence for brain evolution.
The functional properties of an eight subsystem cognitive architecture would have sufficed to handle the cognitive demands of fire use. Individuals would have had the ability to imagine displaced scenarios, a productive form of vocal communication capable of a three party conversation, increasing executive control over action, and extensions of theory of mind and predictive capacities concerning social interactions (2010: s46). Barnard et al. suggest that an eight subsystem architecture “would bear a striking resemblance to Baddeley’s full working memory model” with a central executive controlling interactions between spatial, auditory and verbal information (2007: 1172). A seven-subsystem architecture may have sufficed to control fire. However, other than an increase in control over vocalizations, Barnard and colleagues do not detail the added functions seven subsystems allow (2007: 1171-1172). It is worth noting that in this scheme fire use would have provided an adaptive context and the selective pressure that would have facilitated the change from seven to eight subsystems.

Donald proposes the evolution of mythic cognition from a mimetic precursor around 500 kya (2001: 260). Mythic cognition involves virtually a fully grammatical language, and as such would suffice to solve fire related problems. Mimetic communication would also have sufficed to represent and communicate the required practical and social information. Increasing conscious control over action is associated with mimetic and mythic cognition. Although using different terms, Donald is proposing that collective intentionality and language were well developed in Middle Pleistocene humans. He links increasing cognitive complexity to the increasing complexity of material culture. In this respect we can note that fire use introduced unprecedented levels of material complexity into human life. Controlled fire use increased the cognitive load for humans and changed the context in which human cognition developed and evolved. Below I present a functional model of early human cognition based on the cognitive abilities that I have argued we can infer from fire related behaviours.
Figure 1 A Functional Model of Early Human Cognition Derived from the Cognitive Demands of Fire Use

10.4 Significance of the Thesis

10.4.1 New Directions

I have proposed a heuristic framework for thinking about the kinds of problems fire users had to solve in terms of the cognitive demands required to solve them. To do this I have related realistic behavioural scenarios inferred from empirical evidence to the behavioural criteria used to study cognitive processes in humans and animals. Establishing this framework has been perhaps the most important novel contribution of the thesis. To date no one has tried to relate fire use to a specific and clearly defined set of cognitive abilities. The advantage of adopting this approach is that it allows us to formulate research questions about fire use and prehistoric cognitive processes that are potentially testable, from which we can derive robust rather than speculative inferences.
From this foundation we can now begin to develop more precise models of fire use and its associated costs. Unfortunately, establishing a set of formulae and precise estimates is beyond the scope of the thesis. Before it is possible to pose precise models and questions we need to know exactly what it is we are trying to model. My thesis provides an initial necessary step in this direction by establishing a conceptual framework for developing further research proposals. While my thesis is the first to describe fire use in relation to current cognitive theory, we already have a great deal of relevant information pertaining to early human fire use as described in Chapters Three and Four. We also have models and theories that would be applicable to cost / benefit analyses of fire use. The following issues raised in my thesis are amenable to more precise modeling than I have been able to offer.

Can humans with an encephalisation quotient of about 3.5 to 4.5 (Ruff et al. 1997) or greater survive on a diet of raw food without access to modern amenities? We have some idea of what early human diets were like and the kind of foods raw foodists need to eat to meet their metabolic demands. These can be contrasted to see if uncooked Middle Pleistocene diets would have provided their consumers with enough energy to survive and reproduce. If early human diets were less nutritious, less digestible, too tough or toxic when eaten raw (Luca et al. 2010: 249, Stahl 1984: 156-157), then cooking may have been required to meet energy demands. This may be a tractable problem because we now have a great deal of information about prehistoric diets and their nutritional value (Sutton et al. 2010, Luca et al. 2010, Richards & Trinkaus 2009, Unger et al. 2006, Lev et al. 2005, Stahl 1984).

We also have a good idea of the energy required for a Middle Pleistocene lifestyle (Aiello & Wells 2002), and we know people in different climates expend energy at different rates and that they require more food in cooler climates. The energy a Middle Pleistocene human might expend gathering food and fuel, and just staying alive, can also be contrasted with the energy expended by raw foodists travelling to and from the organic food store. From all this it may be possible to accurately identify when obligate fire users evolved (Wrangham 2009: 96).
A specific cost of interest is how much fuel did fire users need each day? Ofek has suggested (2001: 157) that gathering enough fuel was not a trivial cost for Middle Pleistocene humans. We may be able to estimate the kinds of fuel that they might have used, and how abundant it might have been, from site analyses and paleoenvironmental reconstructions (Berna & Golderg 2007). We have detailed analyses of many sites with evidence for domestic fire and from Middle Pleistocene sites in general. From this we can make estimates about climate, possible fuel loads and the proximity to lithic resources and water. By comparing the distances between cave sites and open-air sites in relation to their proximity to resources, any extra costs associated with cave use can be estimated. There is also ethnographic evidence that can help us estimate how fires were used, how much fuel Middle Pleistocene humans were likely to use and how costly it was to gather (Mallol et al. 2007). All these factors will eventually allow us to more accurately estimate the costs and benefits associated with Middle Pleistocene fire use and make more nuanced estimates about fire related costs than we currently can.

The evolution of Pleistocene humans is marked by a range of costly adaptations that must have been beneficial because these would have been selected against unless the cost benefit / ratio was optimal (Aiello & Wells 2002: 324). Models that try and estimate these costs are applicable to the fire related issues raised in the thesis. For example, Aiello and Wells have considered (2002: 334) the increased metabolic requirements associated with increased absolute body size, increased relative brain size, greater foraging ranges, locomotion and slower rates of pre and post natal development. They suggest (2002: 334) that improved diet, changes in body form, and changes in foraging strategies that may have included economic divisions of labour, may have met the cost of these adaptations. Analyses of this kind can help us to determine if cooking was required to meet the metabolic costs associated with expensive Pleistocene human adaptations as argued by Wrangham (2009).

Central placed foraging models are particularly relevant to fire related costs, and the kinds of strategies fire users could have used (Olsson 2008,
Bird & O’Connell 2006, Winterhalder 2001). For example, these models show that it is better to return with large, rather than small items, even when sources of the latter are more proximate and more easily procured (Winterhalder 2001: 22). This has implications for the kind of fuel gathering strategies Middle Pleistocene humans used, and for determining which strategies would have been ineffectual in some contexts. Costs can be measured relatively accurately given the extensive research directed at understanding the energy costs of locomotion (Grimstead 2010: 65). These models measure distance travelled, time spent walking to and from a patch, and time spent at a patch and body mass in relation to net returns (Grimstead 2010: 65). From these variables the cost of transporting resources and the most efficient of different strategies can be estimated. By using these models, formulae and conservative estimates it should be possible to test my claim that in certain contexts some strategies would have been too inefficient.

Once we have better estimates of fuel costs we can begin to rule out strategies that would not have sufficed in certain contexts. We can move from relative claims that one strategy would have been more efficient than another, to absolute claims that in some contexts a strategy would not have worked. This would help us to know if Middle Pleistocene fire users in particular contexts had to engage in cognitively demanding behaviours involving stockpiling or divisions of labour.

The cognitive significance of domestic fire as a public good is yet to be appreciated. The evolution of social conventions and norms, cultural institutions, collective action and group identification probably depended on the existence of bona fide public goods. Public goods provide the rational and motivation to share goals, collaborate and sanction uncooperative individuals. Evidence consistently tells us that public goods will be undersupplied unless those who refuse to cooperate are sanctioned or social conventions exist to discourage free riding (Shinada & Yamagishi 2007: 330, Fehr & Fischbacher 2004: 186-187, Fehr & Gächter 2000: 980). As a public good, fire use would have facilitated the evolution of social norms and human cooperation.
Game theory can help us understand how fire users solved social dilemmas and managed a public good (Binmore 2007: 64-65). Game theory models attempt to predict the social and economic conditions in which cooperation emerges, and in which cooperation breaks down (Binmore 2007: 76-77). By investigating games of strategy under experimental conditions researchers have been able to show that humans tend to be default cooperators, and will incur costs to punish the uncooperative. However, although most individuals will cooperate initially, around 63% of individuals are conditional cooperators and will cease cooperating if their cooperation is not reciprocated (Kurzban & Houser 2005: 1803). Game theory can also help us understand how social sanctions, divisions of labour or reciprocal exchange mediate, and can evolve from, cooperative interactions. Evolutionary theory, in particular new approaches focusing on multi-level group selection (Nowak et al. 2010: 1057-1062), can also help us quantify the conditions that make cooperation adaptive (Nowak 2006: 1562, Hauert et al. 2008 passim).

The kind of cooperation associated with fire use was probably more cognitively demanding than what we might equate with hunting, foraging or mutual defence, as these could have been driven by proximate motives. Other forms of cooperation, such as cooperative breeding and mutual reciprocity can certainly be adaptive without involving public goods. However, these can be conducted between individuals and do not necessarily improve the inclusive fitness of all group members. To drive selection for the kind of cognition that supports human cooperation, public goods that were not tied to proximate motivations, and that improved the inclusive fitness of cooperators relative to free riders were needed. Controlled fire use provides good evidence for a behaviour that meets both these conditions.

A theme of the thesis has been that fire use would have been very costly in some contexts without the cognitive abilities I have suggested. By developing more precise estimates of the costs fire use involved, along the lines I have described above, the premises supporting my hypothesis can be tested, such as fires are more costly to maintain during winter, the dry season
or in open grassland than at other times of the year, fires are more costly to maintain when food is harder to find, fires are too costly for one or a few individuals to keep going on a day-to-day basis.

I have not considered the cognitive implications of containing fire and the risk of injury an open fire presents. Containment would not always have been an issue. However, in hot, dry and windy conditions when fuel loads were high, fire users would need to be attentive to the danger of starting a bushfire. Fires can cause serious injury and present a high risk to children. Individuals need to be attentive when using or near an open fire lest they or others get burned. Both these conditions provide further avenues through which the cognitive implications of fire use can be investigated in the way I have approached other fire related problems.

10.4.2 New Knowledge

We now have a much clearer understanding of what Middle Pleistocene human cognition was like, when important features evolved and the behavioural context in which human cognition evolved. We can say with confidence that Middle Pleistocene humans were not mindless automata, and that they were not stuck in time. Dehumanizing characterizations of Middle Pleistocene human cognition are not consistent with the fact that these people solved cognitively demanding fire related problems. Fire users could reflect on their situation, had voluntary control over their actions, and could consider future prospects in relation to past successes or failures.

We can be confident that Middle Pleistocene humans were cooperating in humanlike ways that would have required a complex belief / desire psychology incorporating collective intentions. The puzzle of human cooperation is less confounding when we consider controlled fire use. Fire use established an adaptive behavioural context that would have improved the inclusive fitness of cooperative individuals. Fire users had to cooperate in complex ways to enjoy the benefits fire provided. This would have provided individuals with an incentive to cooperate in ways that other behaviour would not have, including a strong incentive to punish the uncooperative.
Our understanding of early human social cognition is greatly improved. Despite the significance associated with the social intelligence hypothesis, other lines of evidence have provided little information about the social cognition of early humans. Potential lines of evidence, such as cooperative breeding are difficult to place in a prehistoric context. Fire use provides evidence for an adaptive behaviour that implies enhanced social cognition relative to that of other apes. From fire use we can now assess the social cognition of Middle Pleistocene humans in terms of an intentional psychology including, a theory of mind, collective intentions and cooperative communicative intentions (Tomasello 2009: 105). Fire use provided a selective context in which the integration of enhanced social intelligence and enhanced general intelligence would have been and adaptive.

In general, fire use provides us with a new way to think about and evaluate the cognitive abilities of early humans. We have only begun to explore the potential of this behavioural adaptation. Fire use involved solving practical problems from which we can infer cognitive capacities and test models and claims about the evolution of human cognitive capacities. Fire use is amenable to co-evolutionary explanations for the evolution of human cognition derived from the considerations of developmental systems theory and the evolutionary conditions described in section 1.5 above.

10.5 Acknowledgments and Concluding Remarks

10.5.1 Acknowledgements

Before making concluding remarks, I would like to acknowledge those scholars who provided the inspiration and point of departure for my dissertation. Gouldsblom has pointed out (1992a) that the transition from passive to active fire use involved a civilizing process. In domesticating fire, humans came to domesticate themselves, by self-regulating their fears, actions and selfish motives. I have developed the idea of self-domestication, by developing its implications for understanding the degree of working memory capacity and executive control early humans had over their behaviour. Both Goudsblom (1989) and Ronen (1998) have proposed that fire use required a form of linguistic communication, to refer to displaced
information, to transmit social obligations and prohibitions, and to organise group level activities. We can now confirm this proposal and go some way to describing the kind of linguistic communication that was required. At base, a triadic form of intersubjective communication involving cooperative communicative intent (Tomasello 2009: 105), ostentation, predication, and displacement was probably required.

Ofek’s observation (2001) that fire use was a costly behaviour and constituted a public good has far reaching implications for our understanding of how human cognition evolved. Few scholars, Sterelny excluded (2003: 137), have picked up on his pertinent observations. I have developed Ofek’s ideas by offering a framework for estimating fire related costs, and by describing in detail the cognitive demands associated with cheater detection and with the forms of exchange fire use could have involved. The cooking hypothesis has served as a basis for several premises of the thesis concerning the timing and social consequences of fire use (Wrangham 2009). As with Ofek’s work, we need to pay more attention to the seminal work of Wrangham and his colleagues in this direction (Wrangham & Carmody 2010, Carmody & Wrangham 2009). I have supported the idea that big brains require cooked foods, and outlined the cognitive consequences of cooking in relation to food stealing and delayed consumption in a fire using society.

10.5.2 Concluding Remarks

My thesis is grounded in empirical evidence for Middle Pleistocene fire use and the kind of behaviours fire use entailed. The conclusions are warranted because fire use can be shown to have involved a range of cognitively demanding behaviours that would not necessarily have been required to forage or make stone tools. They are pertinent because they provide information about human cognition from a time when our understanding of human cognition is limited, and because they allow us to reject or accept previous speculations about the nature of Middle Pleistocene human cognition.
Controlled fire use is one of the most significant behavioural adaptations in human prehistory (Darwin 1871: 855). With the domestication of fire humans now possessed a common good with unprecedented adaptive potential. Latent cognitive potential could now be exploited and existing cognitive skills enhanced.

Fire provided the selective pressure to cooperate with, trust and tolerate others, to think about the future and to act in the interests of the group. In short, more so than any other evident human behaviour from the Middle Pleistocene, fire use provides the earliest reason for humans to start acting and thinking in modern human ways. Without fire the human genus may still be roaming around African and Asian savannahs chipping away at stones, digging up tubers and scavenging carcasses. Virtually none of the things that define our humanity would exist. Language may enable modern human minds, but these minds were forged in the fires of our prehistoric relatives.
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Appendix One

Early Pleistocene sites with possible evidence for domestic fire.

<table>
<thead>
<tr>
<th>Site</th>
<th>Age (OIS)</th>
<th>Age (mya)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chesowanja GnJi 1/6E, Kenya</td>
<td>45 - 47</td>
<td>1.4</td>
<td>Gowlett 1999</td>
</tr>
<tr>
<td>Middle Awash, Ethiopia</td>
<td>47</td>
<td>1.42</td>
<td>Clark &amp; Harris 1985</td>
</tr>
<tr>
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<td>18 - 45</td>
<td>0.7-1.4</td>
<td>Clark &amp; Harris 1985</td>
</tr>
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<td>1.5</td>
<td>Pickering et al 2008</td>
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<td>Olduvai, Tanzania</td>
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<td>1.6</td>
<td>Ludwig 2000</td>
</tr>
<tr>
<td>Koobi Fora FJj 20 Main, Turkana</td>
<td>59</td>
<td>1.6</td>
<td>Bellomo 1994</td>
</tr>
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<td>59</td>
<td>1.6</td>
<td>Isaac 1984</td>
</tr>
<tr>
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<td>Jia 1985</td>
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<td>Gongwangling, Shaanxi</td>
<td>18</td>
<td>.75</td>
<td>Keats 2000</td>
</tr>
</tbody>
</table>

Table 7 Early Pleistocene Sites with Possible Evidence for Domestic Fire

It should be noted that the dates suggested in both appendix one above and two below are mean averages and conditional (James 1989: 6, Rolland 2004: 256-257). Appendix two does not include all the possible sites with evidence of fire use during the Middle Pleistocene. I have not included sites with evidence of fire use such as Torralba and Ambrona in Spain that James placed at 400 kya, but we now think date to after 200 kya (Liubin 1992). See Rolland (2004: 256-257) for a more extensive list of Middle Pleistocene sites with possible evidence for domestic fire, including those dating to between 200 – 126 kya.
Appendix Two
Middle Pleistocene sites with possible evidence for domestic fire.

<table>
<thead>
<tr>
<th>Site</th>
<th>Age (OIS)</th>
<th>Age (kya)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trinil, Java</td>
<td>17-16</td>
<td>650</td>
<td>Oakley 1955</td>
</tr>
<tr>
<td>Jinniushan, China</td>
<td>13-12</td>
<td>450</td>
<td>Zhang 1985</td>
</tr>
<tr>
<td>Vertesszollos, Hungary</td>
<td>11</td>
<td>400</td>
<td>de Lumley 2006</td>
</tr>
<tr>
<td>Terra Amata, France</td>
<td>11</td>
<td>400</td>
<td>de Lumley 2006</td>
</tr>
<tr>
<td>Argo, Cave</td>
<td>11</td>
<td>400</td>
<td>de Lumley 2006</td>
</tr>
<tr>
<td>Cagnyl La Garenne, France</td>
<td>11</td>
<td>400</td>
<td>Perles 1977</td>
</tr>
<tr>
<td>Achenheim “sol 81”, France</td>
<td>11</td>
<td>400</td>
<td>Heim et al. 1982</td>
</tr>
<tr>
<td>Teting, France</td>
<td>11</td>
<td>400</td>
<td>Perles 1977</td>
</tr>
<tr>
<td>Azykh V, Azerbaijan</td>
<td>11</td>
<td>400</td>
<td>de Lumley 1982</td>
</tr>
<tr>
<td>Nadaoutiyah Ain ‘Askar IV, Syria</td>
<td>11-9</td>
<td>400-300</td>
<td>Le Tensorer et al. 2007</td>
</tr>
<tr>
<td>Tabun E, Israel</td>
<td>11-9</td>
<td>400-300</td>
<td>Tsatskin 2000</td>
</tr>
<tr>
<td>Olorgesailie, Africa</td>
<td>11</td>
<td>400</td>
<td>Isaac 1984</td>
</tr>
<tr>
<td>Garba 1 Melka-Kunture, Africa</td>
<td>10-9</td>
<td>350</td>
<td>Chavaillon et al. 1979</td>
</tr>
<tr>
<td>Swanscombe, England</td>
<td>9</td>
<td>330</td>
<td>Oakley 1964</td>
</tr>
<tr>
<td>Mas des Caves, France</td>
<td>9</td>
<td>300</td>
<td>Bonifay 1981</td>
</tr>
<tr>
<td>Kao Pah Nam, Thailand</td>
<td>9-8</td>
<td>300</td>
<td>Pope 1989</td>
</tr>
<tr>
<td>Nyabusora, Kenya</td>
<td>9-8</td>
<td>300</td>
<td>Clark &amp; Harris 1985</td>
</tr>
<tr>
<td>Kalambo Falls, Tanzania</td>
<td>9-8</td>
<td>300</td>
<td>Clark 1965</td>
</tr>
<tr>
<td>Garba, Ethiopia</td>
<td>9-8</td>
<td>300</td>
<td>Clark &amp; Harris 1985</td>
</tr>
<tr>
<td>Cave of Hearths, South Africa</td>
<td>9-8</td>
<td>300</td>
<td>Oakley 1955</td>
</tr>
<tr>
<td>Montagu Cave, South Africa</td>
<td>9-8</td>
<td>300</td>
<td>Clark 1959</td>
</tr>
<tr>
<td>Baume-Bonne mid. II-III, France</td>
<td>8</td>
<td>350-200</td>
<td>Tillet 2001</td>
</tr>
</tbody>
</table>

Table 8 Middle Pleistocene sites dated to 800 – 200 kya with suggestive evidence for domestic fire
Appendix Three

Further details of the sites discussed in Chapter Three.

Gesher Benot Ya’aqov

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**Figure 2.** Composite section of the GBY sequence with correlation to cyclicity of the sequence (c = clay, z = silt, s = sand, g/q = gravel/coquina) and with the presence of burned material (w = burned wood, c = charcoal, f = burned flint); location of the Matuyama-Brunhes chron boundry (MBB) is marked in the section. From Alperson-Afil 2008: 1734.

**Figure 3.** The sequential occurrence of phantom hearths in Layer 11-6 by level, from the topmost (youngest) level 1 to the lowermost (oldest) level 7. From Alperson-Afil 2008: 1736.
**Beeches Pit**

**Figure 4** Schematic succession at Beeches Pit showing the location of the artefacts and burnt horizons together with the environmental history and suggested correlations. From Preece et al. 2006: 488.
Figure 5 Hearths in area AH at Beeches Pit. The arrow indicates the trend of the main series of refits, consisting of thirty pieces, and including two burnt flakes which had travelled forward into a hearth. From Gowlett 2006: 303.

Figure 6 Photograph – hearths in area AH at Beeches Pit. View looking east, showing 77-79E/89-92N, an area of 3 m by 2 m. From Gowlett 2006: 303.
Figure 7 Composite schematic stratigraphical sequence through the Schoningen deposits, which cover the period from the Middle Pleistocene to the Holocene. The sequence (Schoningen 0-VI) is correlated with the climatic cycles (terrace-travertine series) of Bilzingsleben. Key: 1. Denudation horizon; 2. Gravel sands; 3. Sands; 4. Lacustrine deposits; 5. Limnic organogenic sediments; 6. Peat; 7. Travertine; 8. Loess; 9. Soils (Lessive, Pseudogley) and humic zones; 10. Ground moraines; 11. Laminated clay deposits; 12. Periglacial structures; 13. Lower Palaeolithic find horizons (the spears are from level 4 within the Schoningen II sequence and date from the end of the Reinsdorf Interglacial). Lg; Late glacial. Plg; Pleniglacial. Eg; Early glacial. IgI; Interglacial. 1-5: sequence within the Reinsdorf Interglacial. A: arctic; w: warm-temperate. From Thieme 2005: 117.
Figure 8 The site of Schoningen 13 11-4: map of the excavated area at the end of 2003 (c. 3,200 m²). The palaeorelief shows the surface of the chalky mud (layer ‘c’), which underlies the find bearing humic mud (layer ‘b’). The relief is shown in steps of 0.5 m, from 103.00 m to 98.50 m NN. The mapping of the densities of finds (‘1-150’) includes all three-dimensionally and individually recorded object per m² (smaller fragments of bone [< 5 cm] are not included). The mainfind scatter is located on the upper banks of the lake and is more than 50 m long and 10 m wide. H = Hearths (under investigation). Scale in metres. From Thieme 2005: 121.

Figure 9 Photograph – Schoningen 13 11-4: hearth 1 (Ø c. 1m). In the area of the former fire the light grey chalky mud (layer ‘c’), directly below the find-bearing humic mud (layer ‘b’), has turned red (dotted line) and shows ancient shrinking and drying cracks (arrow). The position of Hearth 1 is c. x 683 and y 23 on Figure 8. Scale in cm. From Thieme 2005: 127.
Figure 10 Schoningen 13 11-4: Top Photograph - Two views (a, b) of the 0.88m long wooden stick (Picea sp.) that is carbonized at one end. Bottom - Details (a-d) of the upper part of the wooden stick, showing the extend of the carbonization.
Figure 12 (Top and Bottom Left) Level 6 of Orgnac 3: activity areas according to tools. From Moncel et al. 2005: 1297.

Figure 13 (Top Right) Level 6 of Orgnac 3: activity areas according to accumulation of bone material. From Moncel et al. 2005: 1298.
Figure 14 (Top and Bottom left) Level 2 of Orgnac 3: activity areas according to tools. From Moncel et al. 2005: 1299.

Figure 15 (Top Right) Level 2 of Orgnac 3: activity areas according to accumulation of bone material. From Moncel et al. 2005: 1298.
Figure 16 Synthetic stratigraphical column of Menez-Dregan 1. O: present-day soil; 1: coarse ‘head’ which filled up the deep (it is the last cold period recorded in the site); 2a: large blocks and flagstones, from the final collapsing of the old marine cave; 2b: arenaceous head; 2l: loamy lenses, giving evidence for a loessic deposit, 3a: flaky and argillaceous sand (littoral dune); 3b: Set sandy crust; 4a to 4c: flaky ‘head’ mixing marine sand and pebbles, and also some palaeolithic tools (4b), with strained black layers at the base (4c); 5a to 5d: anthropic soils alternating black (presence of charcoals) and brown layers, very rich with lithic industry (third palaeolithic level); presence, at the top of 5c, of a combustion structure (several flat blocks arranged in a ring); 5e: disturbed ash-bearing layer with combustion structure arranged at the top of the pebble beach. It is the layer which has been dated by ESR; 6: old pebble beach (third beach); 7a: rounded and smoothed blocks from the collapsed cave; 7b: black argillaceous soil (second palaeolithic level); 7c: rounded and smoothed blocks from the collapsed cave, with marine pebbles; 8: old beach with big pebbles and a sandy layer at the bottom (second beach); 9: sandy-loamy layer with lithic tools, bones and charcoals; presence of an anthropic combustion structure in a pit (first palaeolithic level); 10: old pebble beach (first beach); 11: bedrock. Stratigraphic Column from Mercier 2004 et al.: 254, description of sequence from Monnier 1994: 159.
<table>
<thead>
<tr>
<th>Layer/unit</th>
<th>Sample no.</th>
<th>Square</th>
<th>Colour</th>
<th>Depth (cm below datum)</th>
<th>Major mineral components (1)</th>
<th>% AIF (2)</th>
<th>No. phytoliths per gram AIF (ASF (3))</th>
<th>Ratio vl/c (4)</th>
<th>Notes from field observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early Natufian</td>
<td>1aH</td>
<td>M24</td>
<td>White</td>
<td>−205</td>
<td>C</td>
<td>10.5</td>
<td>731,000</td>
<td>0.60:1</td>
<td>Hearth Locus 8.</td>
</tr>
<tr>
<td>Late Natufian</td>
<td>1bH</td>
<td>P26</td>
<td>White</td>
<td>−180</td>
<td>C</td>
<td>9.8</td>
<td>131,000</td>
<td>0.40:2</td>
<td>Hearth Locus 9.</td>
</tr>
<tr>
<td>Late Natufian</td>
<td>1s</td>
<td>P25</td>
<td>Brown</td>
<td>−175</td>
<td>C, CL</td>
<td>31</td>
<td>581,000</td>
<td>0.30:1</td>
<td>Sediment south of Locus 9.</td>
</tr>
<tr>
<td>Late Natufian</td>
<td>2aS</td>
<td>x27y50</td>
<td>Brown</td>
<td>−165</td>
<td>C, CL</td>
<td>35</td>
<td>549,000</td>
<td>0.10:04</td>
<td>Sediment south of Locus 10.</td>
</tr>
<tr>
<td>Late Natufian</td>
<td>2s</td>
<td>N29</td>
<td>Brown</td>
<td>−160</td>
<td>C, CL</td>
<td>31</td>
<td>479,000</td>
<td>0.04:02</td>
<td>Sediment north of Locus 10.</td>
</tr>
<tr>
<td>Mousterian</td>
<td>Layer E. Unit 6</td>
<td>2aH</td>
<td>I19</td>
<td>White</td>
<td>−543</td>
<td>AT, CL</td>
<td>27</td>
<td>625,000</td>
<td>0.60:1</td>
</tr>
<tr>
<td>Layer E. Unit 6</td>
<td>2bH</td>
<td>I19</td>
<td>White</td>
<td>−510</td>
<td>AT, (CL)</td>
<td>29</td>
<td>155,000</td>
<td>0.20:1</td>
<td>Hearth in the same complex as 2aH.</td>
</tr>
<tr>
<td>Layer E. Unit 6</td>
<td>2s</td>
<td>I19</td>
<td>Brown</td>
<td>−540</td>
<td>A</td>
<td>28</td>
<td>690,000</td>
<td>0.80:1</td>
<td>Sediment same complex as 2aH. and 2bH.</td>
</tr>
<tr>
<td>Layer E. Unit 6</td>
<td>2a</td>
<td>I19</td>
<td>Brown</td>
<td>−540</td>
<td>A, CL</td>
<td>33</td>
<td>576,000</td>
<td>0.70:2</td>
<td>Hearth same complex as before.</td>
</tr>
<tr>
<td>Layer E. Unit 6</td>
<td>2s</td>
<td>I19</td>
<td>Brown</td>
<td>−540</td>
<td>M, AT</td>
<td>20</td>
<td>1,280,000</td>
<td>0.50:1</td>
<td>Hearth.</td>
</tr>
<tr>
<td>Layer E. Unit 6</td>
<td>3b</td>
<td>I19</td>
<td>Brown</td>
<td>−525</td>
<td>A, CL</td>
<td>29</td>
<td>714,000</td>
<td>0.70:1</td>
<td>Sediment underneath hearth 3aH.</td>
</tr>
<tr>
<td>Layer E. Unit 6</td>
<td>3s</td>
<td>I19</td>
<td>Brown</td>
<td>−543</td>
<td>A, CL</td>
<td>41</td>
<td>784,000</td>
<td>0.50:4</td>
<td>Sediment beneath 3aH and same level as 3bS.</td>
</tr>
<tr>
<td>Layer E. Unit 5</td>
<td>4a</td>
<td>K2b</td>
<td>White</td>
<td>−480</td>
<td>A</td>
<td>22</td>
<td>678,000</td>
<td>0.40:1</td>
<td>Hearth.</td>
</tr>
<tr>
<td>Layer E. Unit 5</td>
<td>4b</td>
<td>K2b</td>
<td>Yellow</td>
<td>−480</td>
<td>A, AT</td>
<td>31</td>
<td>1,145,000</td>
<td>0.40:1</td>
<td>Sediment close to 4aH.</td>
</tr>
<tr>
<td>Layer E. Unit 5</td>
<td>5a</td>
<td>D24</td>
<td>Yellow</td>
<td>−206</td>
<td>M, AT, CL</td>
<td>49</td>
<td>827,000</td>
<td>0.10:2</td>
<td>Hearth.</td>
</tr>
<tr>
<td>Layer E. Unit 5</td>
<td>5b</td>
<td>D24</td>
<td>Brown</td>
<td>−513</td>
<td>L, CL, A</td>
<td>58</td>
<td>1,404,000</td>
<td>0.70:2</td>
<td>Sediment below 5aH.</td>
</tr>
<tr>
<td>Layer F</td>
<td>6a</td>
<td>I19</td>
<td>Brown</td>
<td>−543</td>
<td>AT, OT</td>
<td>68</td>
<td>151,000</td>
<td>0.60:2</td>
<td>F-sediment.</td>
</tr>
<tr>
<td>Layer F</td>
<td>6b</td>
<td>I19</td>
<td>Brown</td>
<td>−565</td>
<td>OT, CLT</td>
<td>55</td>
<td>609,000</td>
<td>0.40:1</td>
<td>F-sediment—possibly a hearth.</td>
</tr>
<tr>
<td>Outside</td>
<td>7a</td>
<td>Brown</td>
<td>CL, Q</td>
<td>74</td>
<td>27,500</td>
<td>0.40:3</td>
<td>Terra rossa—rendzina. Above cave, close to the chimney.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Outside</td>
<td>7b</td>
<td>Brown</td>
<td>CL, Q</td>
<td>74</td>
<td>16,500</td>
<td>0.50:2</td>
<td>Terra rossa—rendzina. Above cave, higher than chimney.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Outside</td>
<td>7c</td>
<td>Brown</td>
<td>CL, Q</td>
<td>72</td>
<td>12,600</td>
<td>0.40:2</td>
<td>Terra rossa—rendzina. East of cave.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Outside</td>
<td>7d</td>
<td>Brown</td>
<td>CL, Q</td>
<td>70</td>
<td>12,600</td>
<td>0.20</td>
<td>Terra rossa—rendzina. Below the cave.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1. C—calcite; CI—clay; CLT—clay breaking down; L—luteous phosphate; M—montgomeryite; OT—opal transforming to quartz; Q—quartz; A—carbonated apatite; AT—carbonated apatite transforming to CaAl phosphate.
2. % Acid insoluble fraction (AIF) after both acid and oxidation treatments.
3. Number of phytoliths in the Acid soluble fraction (ASF) is shown in parenthesis.
4. Ratio of variable to consistent morphology phytoliths. The first value includes the weathered morphotypes within the variable morphology group, whereas the second value excludes the weathered morphotypes.
Figure 17 Photograph of part of the northern wall of Hayonim Cave showing the hearth complex and the locations of some of the samples. From Albert et al. 2003. 475.
Figure 18 Stratigraphic profile, levels dating and magnetic susceptibility curve from Bolomor Cave. From Peris et al. 2010: 4 Article In Press.
Figure 19 Photograph – Exposed burnt flints and bones at Misliya Cave. From The Misliya Cave Project Website.

Figure 20 Photograph – Hearth area at Misliya Cave. From The Misliya Cave Project Website.
Appendix Four

Figure 21 Outline of the argument structure in relation to the premises and conditions discussed throughout the thesis.
Appendix Five

Ape Interactions with Fire.

It is important to consider if other apes can control fire for two reasons. First for what it can tell us about the capacity of early hominins to control fire, and second because I have argued that the cognitive capacities required for controlled fire use are beyond those of the other great apes.

Two chimpanzees in the Johannesburg Municipal Zoological Gardens in the 1950’s were addicted to smoking cigarettes. The older chimpanzee, Bango, picked up the habit from his original owner, whereas Tyrus acquired the behaviour from cigarettes provided by his handlers and zoo patrons. Bango and Tyrus were clearly addicted to smoking. Both Bango and Tyrus learned independently to keep butts burning so as they could light dead butts and new cigarettes. The also learned to extinguish any smoldering butts that presented a fire danger. Patrons would often throw lit cigarettes into the cages to see these apes smoke. Both chimpanzees could handle cigarettes adeptly without burning themselves and to keep short butts alight until they had satisfied their desire to smoke. Both apes seem to have acquired these behaviours through imitating humans and trial and error learning (Brink 1957: 241-247).

Kanzi, the famous language trained bonobo, is reported to have used fire. On an outing in the forest Savage-Rumbaugh reports that Kanzi touched the signs on his symbol pad that indicated marshmallow and fire. When provided with marshmallows and matches he is reported to have snapped twigs, then lit them with the matches and toasted the treat on a stick (Raffaele 2006). Captive chimpanzees being reintroduced into the wild are also reported to have tended rudimentary fires to cook and keep warm (Brewer 1978: 174, 176). As with the smoking chimpanzees these apes seem to have acquired this behaviour through both imitating humans and invention. In these cases fire use is only possible because humans provide both models and necessary materials. The apes in question also seem to be seeking immediate
gratification, and understand that fire is the means to achieve it. The smoking apes only keep butts going when they are in the process of smoking. Once satisfied they would cease this behaviour and ignore any butts thrown into their cages unless they presented a fire danger (Brink 1957: 243).

Captive chimpanzees that were unfamiliar with fire have been exposed to fire under safe experimental conditions, and their reactions observed. Over a period of four days, experimenters established a small fire in one enclosure then allowed the chimps to interact with it. These apes were not provided with any fire related rewards, such as tasty treats, and they were not provided with any information about how fire can be used. The initial response of the apes to the fire was excitement, with lot of running about and whooping and the fire eventually being scattered about. On the next two days the chimpanzees became more curious and composed, taking time to inspect and play with the fire. By day four their curiosity had faded and the apes ignored the fire and went about their usual business (See Burton 2009: 31-33 for a review of the experiment).

Wild chimpanzees at Fongoli, Senegal have been observed calmly monitoring wildfires and changing their behaviour in anticipation of the fire's movement (Pruetz & LaDuke 2010). This provides important information about the spatial abilities of apes to monitor fire, and their capacity to control any fear fire might induce. We also know that chimpanzees will exploit the aftermath of a wildfire (Brewer 1978: 232), as do many animals. The black kite is reported to pick up smoldering twigs from wild fires and drop these to spread the fire and flush out prey (Goudsblom 1989: 169).

These observations suggest that early hominins were capable of making a positive association with fire and some reward, learning important properties of fire and handling fire safely. These were all important attributes for controlled fire use to evolve from passive fire use. Burton has investigated in detail how early humans may have became interested in fire and learned to control it (Burton 2009 passim).
However, these examples do not imply that other apes have the cognitive capacity to resolve fire related conflicts of interest, social dilemmas, planning, or the many social problems associated with future directed group level cooperation (Wrangham & Carmody 2010: 197). They do not suggest other apes could solve the fire related problems discussed in the thesis. Controlled fire use is a uniquely human behaviour that requires uniquely human cognitive skills. Controlled fire use and other distinctive human behaviours of the Pleistocene probably facilitated the evolution of human cognition.