Core High-Level Cognitive Abilities Derived from Hunter-Gatherer Shelter Building

Jerald D. Kralik
Korea Advanced Institute of Science and Technology

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Jerald D. Kralik (jerald.kralik@gmail.com)
Department of Bio and Brain Engineering
Korea Advanced Institute of Science and Technology (KAIST), Daejeon, 34141, South Korea

Abstract

Determining the fundamental cognitive abilities underlying human high-level cognition remains elusive. An examination of the main activities of our first *Homo sapiens* ancestors offers a normative approach. Because shelter building was critical for a nomadic hunter-gatherer and required comprehension and manipulation of the knowledge for predicting, controlling and creating, I examined shelter building. I first conducted a theoretical analysis of the necessary steps to imagine and then construct a temporary shelter in the African savanna, including the underlying cognitive abilities to do so. I then compared the results to a case study of grass-hut building by a modern-day San tribe community in Botswana, Africa. The analysis provides a set of core cognitive abilities required for shelter building, which may represent the core cognition underlying our physical intelligence. Future examination of the other primary activities of our first ancestors should help produce a complete list of our fundamental high-level cognitive abilities.

Keywords: High-level cognition; cognitive modeling; evolutionary psychology and neuroscience; anthropology.

Introduction

There have been significant advances in the study of high-level cognition — such as in attention, decision-making, reasoning, and creativity (e.g., Gazzinga, Ivry, & Mangum, 2013; Glimcher & Fehr, 2014; Helie & Sun, 2010; Holyoak & Morrison, 2012; Kralik, 2017; Kralik, Mao, Zhao, Nguyen, & Ray, 2016; Laird, Lebiere, & Rosenbloom, 2017; Russell & Norvig, 2010; Silver, Schrittwieser, Simonyan, Antonoglou, Huang, et al., 2017; Tenenbaum, Kemp, & Griffiths, 2011) — yet much remains unknown. This is especially borne out when considering current computational approaches to human cognition, with many appearing to assume that high-level cognition will arise from, for example, deep hierarchical neural networks based on associative processes. Indeed, there remains no consensus on how to model higher-level cognition, with current AI systems falling far short of human-level abilities.

What then is the best approach to identify and delineate the actual core cognitive processes underlying human high-level cognition? Researchers attempt to focus on tasks that require the highest levels of our abilities, with recent examples including video games, the game "Go", and autonomous driving (Silver, Schrittwieser, Simonyan, et al., 2017). Such approaches are valuable, but still run the risk of missing critical high-level capabilities. For example, most work concentrates on the derivation of complex action policies with a well-defined problem representation, and yet the generation of the appropriate problem representation itself is one of the most challenging problems animals (including humans) face in a potentially intractably complex real world (Kralik et al., 2016; Kralik, Shi, El-Shroa, & Ray, 2016; Sampson, Kahn, Nisenbaum, & Kralik, 2018).

Ideally, we would take a more normative approach to determine the task paradigms that best capture the fundamental nature of human high-level cognition, but to do so, it would require isolating our fundamental abilities from learning and cultural influences. For example, high-level mathematical prowess consists of both basic cognitive ability as well as substantial knowledge and skills developed from teaching and practice: i.e., from learning. How then might we isolate basic abilities from subsequent learning and cultural effects? Two possible approaches are developmental and evolutionary ones. Notwithstanding important work studying the developmental process (e.g., Tenenbaum, Kemp, & Griffiths, 2011), the approach faces limitations in that the brain is normally not fully developed, and thus developmental and learning effects accumulate. An evolutionary approach points us to biological anthropology and the evolution of *Homo sapiens*. That is, substantial evidence strongly suggests that the human brain largely finished evolving in Africa during the Pleistocene epoch (roughly 100,000 years ago), when humans were hunter-gatherers (Buss, 2015; Dunbar, 2003; Nowell & Davidson, 2010; Relethford, 2013). Thus, in principle, if we could examine the cognitive abilities underlying their main activities, we could potentially identify the core set.

To conduct such an analysis in the modern day is indeed a challenge, yet is possible via a triangulation of multiple lines of evidence: e.g., analysis of the actual Pleistocene archaeological evidence (e.g., the surviving toolkit) (Buss, 2015; Kralik, 2017; Nowell & Davidson, 2010; Relethford, 2013), logical analysis of the problem being solved, such as building a shelter using only natural elements in the local environment (e.g., Kalahari desert), and testing these analyses against modern-day examples of 'authentic' traditions passed down to current times (e.g., how to build a traditional grass hut). Regarding the latter — testing modern-day cases — given the potential diversity of solutions throughout the world, the tribes targeted for analysis can be a critical factor. Although all are valuable in helping to uncover universal abilities all humans inherited, the cleanest attempt would be to examine those most closely related to our earliest ancestors; and recent genetic evidence identifies the San/Khoisan tribes as the oldest (Schuster, Miller, Ratan, Tomsho, Giardine, et al., 2010). Of course, studying the modern San to uncover the abilities of ancestral *Homo sapiens* carries the assumption that their traditional activities reflect the original ancestral solutions (due to facing the same problem and solving it directly, logically and efficiently), but this assumption could be false. However, the assumption can also be tested if we first conduct a theoretical analysis of how a core activity would be carried out, and then compare the conclusions to a modern-day case study.

In the current paper I take this approach by examining a core activity of the San, with the goal of identifying the basis set of the highest abilities of the human mind (prior to the accumulating effects achieved via learning processes, teaching, and culture). In the following sections, I first identify shelter building as a fundamental task to be examined. I then provide a theoretical analysis of shelter building, and then present the core cognitive abilities underlying human physical intelligence identified by this analysis. I then compare the results of this analysis to a case study of grass-hut building by a San tribe in Botswana, Africa (Pratchett, 2017). Future work that examines the other key activities of the San (such as medicinal knowledge and practices, cooking, social interactions, and fire, tool, houseware and jewelry making) will be needed to provide greater assurance that the list is complete for human higher-level cognition (Buss, 2015; Kralik, 2017; Relethford, 2013).

Why Shelter Building?

With the ultimate research aim to analyze all of the presumed major activities of ancestral humans, I nonetheless chose shelter building first for multiple reasons. Firstly, it is important to examine a task that appears most complex, and thus most taxing of our cognitive abilities. For example, it should require more than just to seek or forage and extract, with evidence suggesting these are not sufficiently complex to explain higher cognitive abilities (Dunbar, 2003). In addition, the activity ideally would be carried out by both men and women since our interest is with core universal human abilities, not more specialized cases. In fact, shelter building is intriguing not only for the apparent complexity involved, but that both sexes engage in it (and if anything, mostly by the women) (Pratchett, 2017). Finally, the activity should reflect not only understanding for prediction, approach, attainment or avoidance, but also significant *manipulation* for our own ends: i.e., controlling and creating.

These considerations nonetheless point to multiple activities, such as basic social interactions, which we have also begun examining (Lee, Kralik, & Jeong, 2018). However, an additional reason for selecting shelter building is the obvious need of our first ancestors to avoid the elements and danger as a large ape previously adapted to arboreal life in an environment turned from rainforest to woodland to savanna, with relatively little protective weaponry or terrestrial escape mechanisms: indeed, as a proverbial fish out of water. Being so exposed (with respect to heat, cold, weather, danger), natural shelters obviously had to be used, including some trees and rock formations (like caves); yet as the woodland turned to savanna these options become limited, especially if one must remain nomadic to follow food and water patterns and protect larger families. Thus, it is apparent that there was great pressure for creative solutions.

Shelter Building Analysis

To visualize a simple shelter, Figure 1 is a general illustration from the theoretical analysis, with the main elements labeled.

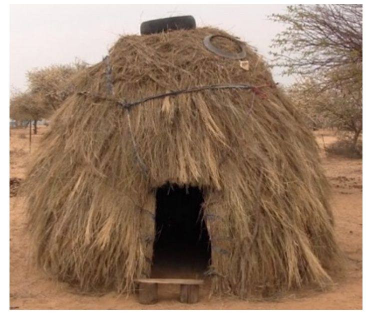

Figure 1: A shelter from the theoretical analysis.

The initial problem then is this: when facing elements and threats to be avoided — e.g., rain, heat, cold, predators — how would the first ancestors come to the realization that a shelter could be built? The first step is likely initial observation when in a natural shelter, like a cave or under trees (e.g., in downpour, such as during the rainy season), with the realization that it will have to be abandoned to move on to regions that may not contain such shelter (as nomadic hunter-gatherers in the African savanna). Under such a scenario, they then at some point must wonder, “couldn’t we just recreate one ourselves?”

And this would require, cognitively, to construct a new problem representation with a creative, novel solution. For example, the initial action set called to mind in a downpour would be various means to seek shelter: e.g., locate a cave or sufficient tree canopy, perhaps check for safety, then move inside or under. How then could this state set (e.g., caves, tree canopies) and action set (e.g., find, enter) be expanded, ultimately to the point of creating a shelter themselves?

To focus on a specific scenario, consider seeking shelter under trees in a downpour (with results the same for other specific cases, such as with a cave). The process of coming to shelter building, then, would appear to begin with the question, “what is stopping the rain?” The answer would require an examination of the interaction between the rain and what is blocking it, i.e., the tree leaves. More specifically, it would require an examination of the contact site of collision and determining what is happening, i.e., the reason for the leaves’ effectiveness, and thus the mechanism of interaction. Without the luxury of trial-and-error learning, and effectiveness at a premium, simple associative processes are not sufficient (Passingham & Wise, 2012). In other words, to be successful and efficient, our ancestors would need to identify the actual *causal relationship* — the specific mechanism of interaction — and do so in an efficient manner (reasonable amount of time, minimal errors). It thus requires *Homo sapiens the scientist*, with two critical characteristics: (1) manipulation of ‘trials’ as experimental tests of hypotheses to isolate the causal factors from confounds; and (2) an ability to identify the actual causal agents and their effects. Then consider each of these in turn. First, an experimental approach to problem solving would require a meta-view of the problem, i.e., manipulating the overall problem representation and analysis of it: e.g., considering independent and dependent variables, organizing 'trials' to test their relationship, and recognizing such relationships (e.g., linear, nonlinear). Thus, ***metacognition*** is required. Moreover, such designing of experiments would also require ***mental simulation*** and ***planning***.

For the second characteristic, a proper experimental analysis would nonetheless lead to nothing visible — i.e., no perceptual features could be identified that cause the successful blocking of the rain (e.g., green color, shape). In short, it leads to a determination that there are unseen ***causal agents & forces*** (Kralik, 2017). More specifically, rain blocked by a leaf, even intuitively, would be represented as a ***collision of two counter forces driven by two underlying causal forces*** animating the rain (i.e., giving it strength and movement force) and fortifying the leaves (i.e., producing the strength and repellent properties): i.e., if R_1 = *causal relation* (as collision), and F_i = force produced by causal agent, then $R_1(F_1(\text{assumed causal agent}_1, \text{leaf}), F_2(\text{causal agent}_2, \text{rain}))$, simplified as $R_1(\text{leaf, rain})$ or R_1. Of course, the underlying electromagnetic forces could not be truly understood (they aren't even so now), but a proxy can be used and labeled, e.g., as a "spirit" or "essence." Indeed, all objects would now be considered as entities consisting of underlying causal agents that animate them, producing the forces that lead to their interactions, i.e., their dynamics. Thus, a kind of *animism* is anticipated not just as a religious point-of-view but as a universal cognitive construct derived from causal reasoning. Indeed, it is interesting to note that animism is thought to be universally shared by all indigenous tribes around the world (Relethford, 2013).

This theoretical understanding, then, requires the ability to ***imagine hidden causal agents*** and their ***resulting forces*** that lead to changes in objects that can be observed (Kralik, 2017). In addition, to isolate and identify these hidden causal agents, ***reductionism*** and ***inductive reasoning*** are also required. Moreover, an understanding of the relationships of causal agents from observations of specific cases (i.e., trials) requires ***abstraction*** to view (a) the specific cases from observations as an 'ordered set', and (b) the relationship between two ordered sets (e.g., a linear relationship between the independent and dependent variables).

The second major step toward shelter building is comprehending the 'roof': i.e., how the leaves are held overhead. The answer is that each leaf is held by a stem: $R_2(\text{stem, leaf})$; then stem held by branch: $R_3(\text{branch, stem})$; and, thus, branch with leaf as $R_3(R_2(R_1))$. $R_2(R_1)$, then, is a first ***nested causal relation***: i.e., ***relation of relation*** (and note a *tool* control structure).

Third, a branch with multiple stems and leaves is comprehended as $R_4(R_3(\text{branch}, R_2(R_1) * X))$, with R_3 representing adherence and R_4 ***a configuration of multiple*** (i.e., X) ***nested relations***. Importantly, a key mechanism by which the mind manages these embedded relations is via ***chunking***: e.g., "R_4(etc.)" is considered a 'branch with leaves', multiple branches with leaves across adjacent trees a 'canopy', and its ability to block the rain a natural 'roof'. It is a powerful type of naming that reflects ***symbol use*** and a capacity for extensive ***cross-referencing*** (Kralik, 2017).

Fourth, one must understand how trees are held upright: $R_{7\rightarrow1}$, where R_5 = larger branch (or bough), R_6 = tree trunk (and roots), R_7 = ground (i.e., roots into ground). This extended hierarchical tree data structure reflects not only nested relations, but more clearly ***recursion*** (i.e., nested subtrees).

Fifth, now these separate tree structures (both figuratively and literally) need to be configured together to form a canopy (i.e., a more complete roof): $R_8(R_{7\rightarrow1}, R_{7\rightarrow1}) \Rightarrow R_8(\text{'}R_{7\rightarrow1}\text{,'} * X)$, where R_8 = circular configuration in ground of multiple (i.e., X) bough-branch-leaves structures (i.e., beams) to construct the 3D structure. R_8 is a ***relation of more clearly separate hierarchical relations***, i.e., of each tree structure or beam — a *forest* in graph-theoretic terms.

Sixth, an entrance would be needed: i.e., opening in the natural shelter under the trees to reach it (and eventually made in the hut), which is a comprehension of a new configuration of the larger one (i.e., of the larger 3D structure of the shelter) — and thus 'forests' can also be included or embedded in other relationships.

At this point the general structure of the natural shelter is understood. Thus, to actually build a shelter, this understanding is first necessary (*Homo sapiens* as scientist). But then to build it, other cognitive abilities are required — i.e., *Homo sapiens must now become the engineer*. The seventh consideration, then, is a particularly critical one. To convert the knowledge into actual construction, in brief, the key mechanism appears to be ***substitution*** of causal agents, i.e., a matching of forces and actions across different objects (i.e., via their underlying causal forces, and thus their *actions* or *forces*), and the ability to then swap causal agents (and thus various interacting objects, including self) among the roles. Indeed, the first component, matching, is essentially the comprehension of ***analogies***, i.e., matching the relations of different agents across content domains: like wind blowing branches as if carrying them. In fact, normal generalization abilities are important here but appear too limited to provide sufficient matching of actions between different causal agents (including oneself), especially across all biological and nonbiological objects of interest. Thus, ***abstraction*** is again needed to reach a level sufficient to enable matches across different objects (i.e., via their underlying causal forces, and thus their observed actions). Abstraction is reflected in concepts like hit, push, throw, drop and collide.

In addition, note that this substitution mechanism also uses explicit knowledge about *self* — e.g., labeling self as agent and modeling our own actions and relations — thus revealing ***self-reflection*** and ***self-representation*** capability (with both a type of metacognition). Moreover, when considering *action* in more detail, action selection is not merely choosing one action element from a set given the current state; rather, we need to mold actions according to affordances of a target, producing an embedded problem of 'how do I generate the necessary action (configuration)?' (Kralik, Muldrew, Gunasekaran, & Lange, 2017). In other words, we have A_1(Self, Body), where Body = action configuration, such as that for reaching and grasping, with A_1 = actual action performed. If we substitute "Mind" for "Self", and convert A_1 to the actual underlying force it generates, F_1, the manipulation of an external object would actually be: $R_1(F_1(\text{Self=Mind, Body}), F_2(\text{causal agent}_2, \text{Target}))$, where R_1 = manipulation of the external object to create the desired dynamic change (producing the collision of forces between the two 'objects').

The second component of the substitution mechanism — substitution *per se*, and in particular when *self* is substituted in — is the key contact point, or pivot, between cognition and action. Indeed, it is related to the well-known mirror system discovered initially in rhesus monkeys (see Gazzinga, Ivry, & Mangum, 2013). However, in the current case it is significantly more sophisticated: for example, relating to hidden causal agents and forces, abstraction, self, and flexibility (i.e., much less "mirror"-like as a process).

In fact, the substitution mechanism appears to be a key means by which humans are able to manipulate the problem representation and problem-solving process, especially regarding adding elements to the representation (e.g., new states, stimuli, and actions). This would be expected to occur particularly during the 'scientist-experimental' periods, in which the individual is discovering new causal relationships and the causal agents underlying them (and then mapping the findings to one's one actions, often with the help of abstraction). (Another critical means to manipulate the problem-solving process is with the use of *levels* of cognitive systems, with each level having particular problem elements; Kowaguchi, Patel, Bunnell, & Kralik, 2016; Kralik, 2017; Kralik, Shi, et al., 2016; Sampson et al., 2018) Indeed, not only does the substitution mechanism provide a means by which observation of external behavior can be converted into novel actions and creative solutions, it is another example of how perception and action appear more closely aligned than typically appreciated.

Substitution and causal understanding of the underlying imagined causal agents and forces, then, enable inserting oneself (or other agents) in various places in the nested causal relations when necessary, enabling shelter construction. For example, cutting and collecting branches could occur after observing the effects of wind, and replacing it with self; or even matching one's own behavior from different circumstances, such as moving smaller branches, and then replacing the smaller with larger ones for shelter beams. This would continue at each step, e.g., configuring the beams in a circle, inserting into ground, etc. In short, the entire construction process can result once there is a proper causal understanding of each component, followed by a matching then replacement of causal agents by self or other agents.

Eighth, with a basic shelter structure in place, branches must also then be further incorporated, interleaved for reinforcement (and walls), and then more leaves are needed for covering the entire structure, including the walls. This step requires a consideration of stability and strength of the structure as a whole, and ***using relations to produce a heightened combined force***, F_x, to properly counter opposing forces (e.g., wind or gravity). Thus, $R_2([R_1(F_1(\text{assumed causal agent}_1, \text{cross branch}), F_2(\text{causal agent}_2, \text{beam}))], F_3(\text{causal agent}_3, \text{wind}))$.

Ninth, further reinforcement by *tying down* is needed, driving the desire to obtain a type of rope or twine, which would provide critical stability for the overall structure. In fact, this step is a clear example of additional ***subproblems***, especially for refinements of the overall structure. For example, the twine must first be prepared, such as from animal intestine, vines, or tree bark. These subproblems, then, reflect ***insertion of nested relationships***, comparable to means-end analysis (Russell & Norvig, 2010). Indeed, there are multiple subproblems (refinements), including determining the type of tree; type of external covering, i.e., leaves vs. grass (and species type); tools (such as axe, cutters), including their manufacture (Kralik, 2017; Nowell & Davidson, 2010; Relethford, 2013); and help from others, i.e., coordination of activities (Shi, Sauter, & Kralik, 2009; Shi, Sauter, Sun, Ray, & Kralik, 2010; Sun, Mao, Ray, Shi, & Kralik, 2011).

Tenth, in fact, all materials must be acquired first and the structure built in opposite order: e.g., holes being made in the ground, beams inserted into them, reinforcements made (i.e., walls), and then covering added. Thus, beginning with a need for a covering or roof as the original problem, construction yet proceeds in the opposite order, with the roof (and overall covering) produced as a final step. This again reflects mental simulation and planning, as well as — especially with respect to obtaining the needed materials — ***search, select, sort and 'data' organization processing*** abilities.

Finally, 'understanding' can provide an accurate description of what is observed (e.g., causal mechanisms of rain and tree dynamics), but to manipulate this understanding for one's own needs and capabilities (e.g., having action, size, and strength constraints of the human body), ***flexible manipulation and modifications of this knowledge*** is necessary. For example, it would not be feasible to use larger tree trunks as shelter beams, and instead, larger branches (boughs) must be acquired and inserted into the ground. Thus, further cognitive manipulation abilities are needed. Focusing on having a series of nested relations (e.g., $R_{8\rightarrow 1}$), these include the ability to produce *deletions, insertions, replacements (substitutions), inversions, sections moved and rearranged, duplications*, and perhaps most notably *chaining*, which provides the transitivity necessary for another critical capacity: ***deductive reasoning***.

Core High-Level Cognitive Abilities

From the theoretical analysis of shelter building, we obtain the list of 18 core abilities shown in Table 1.

Shelter Building Case Study: San Grass Huts

Based on logic and efficiency, one might expect minimal shelters to be produced in a highly circumscribed way, as just enumerated. Nonetheless, it is important to attempt to obtain empirical evidence to test these conclusions. To do so, I examined one case study of grass-hut building by a San tribe (i.e., the *ǂX'ao-||'aen* in Botswana, Africa), in which one village member described the process as they build one in a video produced by an anthropologist who studies their lifeways in the field (Pratchett, 2017). Although it is possible that the shelter building of this modern San tribe community may be significantly different from that of our first *Homo Sapiens* ancestors, the extent to which their process matches my theoretical analysis should help to validate a basic process that would be expected to have been utilized by the original ancestors (based on the fundamental constraints of the problem, combined with a simple, logical and efficient solution). Table 2 lists the construction steps.

Table 1. The high-level cognitive abilities for shelter building.

1.	**Problem solving and Decision making**
2.	**Metacognition (for meta-problem-solving, i.e., manipulating the problem representation)**
3.	**Mental models, Simulation, & Planning**
4.	**Hidden causal agents & forces, with interaction as collision: Animism as intuitive physics**
5.	**Reductionism & Inductive reasoning**
6.	**Abstraction**
7.	**Analogies (from matching at higher levels of abstraction)**
8.	**Self-representation and Self-reflection**
9.	**Substitution (of causal agents, including self, into relations)**
10.	**Nested causal relations: i.e., relations of relations**
11.	**Chunking, Symbolic processing, Cross-referencing**
12.	**Recursion**
13.	**Configurations of multiple nested relations (i.e., a 'forest'): Relation of more clearly separate hierarchical relations**
14.	**Using relations to produce heightened *combined* force**
15.	**Subproblems: i.e., insertion of nested relationships**
16.	**Search, Select, Sort and 'Data' organization processing**
17.	**Flexible manipulation and modifications of knowledge: e.g., deletions, insertions, replacements (substitutions), inversions, sections moved and rearranged, duplications**
18.	**Deductive reasoning**

Theoretical and Case Study Comparison

Overall, the theoretical analysis of shelter building closely matches the case study, including material preparation, branches inserted into ground holes as beams, cross branches as reinforcements and walls, a roof, entrance, a fully covered structure (via leaves or grass) to protect from the elements, and a rope or twine to hold everything more firmly in place. In fact, further details from the case study provide even more interesting information regarding the 'refinements' or subproblems mastered, such as attention to the functional properties of specific tree and grass species, replacing the leaves with grass, the process of adding the grass, and a process used to produce twine. Nonetheless, all such additional details are readily explainable by the core cognitive abilities derived, such as replacing the leaves (observed overhead) with grass (from the ground).

The one core cognitive ability that may be less apparent in the case study is (5), i.e., actual appreciation and use of hidden causal agents and their generated force interactions among the objects (versus a simpler use of the functional properties of objects). However, multiple lines of evidence appear to reflect the deeper intuitive physics understanding. The most critical evidence found in the case study is that for *reductionism*, in which, e.g., objects are seen as a combination of parts (and the unseen 'glue' holding them together), enabling the preparation of parts as needed, including cutting branches; and then even further, the parts being seen as a combination of materials (enabling the most flexible consideration and manipulation of them). A similar assessment was derived from a detailed analysis of tool manufacturing and use from archaeological and anthropological evidence (Kralik, 2017). Put differently, we see the effects of unseen causes daily, such as the effects of gravity, and the causal mind requires a reason for them. A satisfactory explanation requires the supposition, the assumption that the causal agent must be unseen, invisible to the naked eye, which we label with an arbitrary symbol such as "spirit" or "essence" (or "force" or "gravity"). And as stated, this understanding relates to *animism* as a way of thinking, which is thought to be universally shared by all indigenous tribes, and is so by the San (Relethford, 2013).

Table 2. Actual San grass-hut construction.

1. Collection and preparation
- Gather particular species of grass as clumps (i.e., with roots), and branches of a certain tree (Za'o, Terminalia sericea) for strength and insect resistance, cutting them from trees
- Clearing for shelter entirely of sand
- Make twine (for tying into place)
  -- From the fibers of the Za'o tree
  -- Or from a succulent plant (!hui).
    --- To prepare: soaked in water to soften, then beaten with pestel to expose a stringy inside, which is then twined to form the rope (for multiple purposes) (Lee Pratchett, personal communication).

2. Holes in ground, circular configuration, with digging stick, hands

3. Branches inserted in holes
- From pile of branches, inspecting for long and "bendy" ones, taking apart further if needed
- Place in holes according to size and height as "pillars"
- Fill holes to hold branches firmly
- Checking overall structure throughout

4. Roof
- Holding the branches together, bending them, and tying tightly with rope
- Further thatching with twigs and branches: i.e., adding smaller twigs and branches at the top

5. Entrance
- Wrapping smaller branches, bending and tying them (with rope) for opening
- Adding grass to "door"

6. Reinforcement, walls
- Adding more branches throughout to make the sides and top stronger ("tough and firm"), entwining them among the others (some perpendicular to beams but all directions), larger ones lower

7. Grass exterior
- First digging trench around outside to support grass at bottom, then covering with sand after inserting bottoms (i.e., the root clumps)
- Then cover the "house" by turning the grass clumps upside down, interleaving the top of the grass with the layer below
- Using stick to reach the top, "to make grass on top firm and stop the rain coming through"
- Then using larger twine to wrap around outside and tie down structure, "to avoid the wind blowing the grass away"

8. Checking and cleanup
- Checking for holes, sharp edges, sweeping debris on ground

In sum, the high theoretical and case study similarity suggests that simple shelter building yields a solution with universal principles: like a configured foundation, cross-beam reinforcements, roof, entrance, and outer covering to protect against the elements. These basic components in turn reflect fundamental cognitive abilities required to comprehend, imagine and produce them.

Discussion

Eighteen core cognitive abilities, therefore, appear to be necessary to produce the types of shelters made by our original *Homo sapiens* ancestors, and thus constitute at least a partial list of what our minds were designed by evolution to do: in this case, to avoid a broad array of potential threats, from climate (e.g., temperature control and inclement weather) to other organisms (e.g., predators), especially at night — in the dark, and during sleep. How likely is this list complete? If we accept that an analysis of the key activities of the ancestral *Homo sapiens* should produce the core cognitive abilities, then the current findings would minimally be a necessary initial step in identifying the fundamental abilities in a way that perhaps best isolates them from possible effects of learning and culture. Of course, learning also took place among the ancestral humans. This is in fact why it is also important to attempt theoretical analyses of the problems they solved. At the same time, it is nonetheless important to assess the theoretical results with empirical ones when possible. In fact, current genetic evidence identifies San tribes as those most closely genetically related to our original ancestors (Schuster et al., 2010), and the activities from their hunter-gather lifestyle (either currently or more typically as passed down knowledge from hunter-gather times) likely reflect solutions in the Pleistocene. And yet many modern anthropologists and indigenous tribes and their advocates adamantly emphasize that their customs also reflect vast cultural evolution over time. This caveat is important and again shows why it is also critical to attempt a theoretical analysis prior to an empirical one based on any modern tribes. The fact that I obtained such a close match between the theoretical analysis and empirical description suggests that the problem itself likely produces comparable solutions (assuming a logical and efficient one).

To determine whether Table 1 is complete, other San activities that reflect ancient hunter-gather ones also need to be examined. These include fire making, cooking, houseware (e.g., pots) and tool making/manufacture, jewelry making, medicinal knowledge, and social interactions. There is indeed valuable information on most of these, but a detailed examination of the necessary underlying cognitive abilities is needed. An additional critical question that such future findings should shed light on is the extent the mind/brain is organized around general versus specialized content domains. A direct comparison of the generated lists of necessary cognitive abilities should provide some clarity.

In considering the novelty of the current findings, it is of course true that all items in Table 1 are well known and actively studied (e.g., Gazzinga, Ivry, & Mangum, 2013; Glimcher & Fehr, 2014; Helie & Sun, 2010; Holyoak & Morrison, 2012; Kowaguchi et al., 2016; Kralik, 2017; Kralik, Shi, et al., 2016; Kralik, Mao, Zhao, Nguyen, & Ray, 2016; Laird, Lebiere, & Rosenbloom, 2017; Russell & Norvig, 2010; Sampson et al., 2018; Silver, Schrittwieser, Simonyan, Antonoglou, Huang, et al., 2017; Tenenbaum, Kemp, & Griffiths, 2011). However, to my knowledge, no current AI system is explicitly based on these 18 core abilities. For example, most systems build knowledge structures around objects, more than around the underlying causal agents animating the objects (although see Battaglia, Hamrick, & Tenenbaum, 2013). Of course, the functional properties of objects are utilized, but the argument here is that they have to this point perhaps been too subordinated to basic object knowledge. Exactly what this means in terms of applicability will require a computational implementation of such a system (i.e., based on Table 1), which I am currently undertaking. Indeed, a computational implementation will also help determine whether such core cognitive abilities are actually sufficient to then simulate, together with learning and cultural knowledge, more of our higher abilities and achievements (such as an understanding of higher math, and from building shelters to spaceships).

Finally, a major thrust of this research program is an attempt to better understand how problem representations themselves are generated and modified (Kralik, Mao, et al., 2016; Kralik, Shi, et al., 2016; Sampson et al., 2018). This critical problem appears to be understudied, and yet one that appears to have been enduringly confronted by our ancestors: 'how do I solve a problem that I never faced before, being a fish-out-of-water as a large and relatively defenseless ape adapted for arboreal life?' In any event, it is believed that the approach advocated here should complement others with the aim to uncover and eventually simulate the highest abilities of the human mind and brain.

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