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The Social Trackways Theory of the Evolution of Human Cognition

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Abstract Only our lineage has ever used trackways reading to find unseen and unheard targets. All other terrestrial animals, including our great ape cousins, use scent trails and airborne odors. Because trackways as natural signs have very different properties, they possess an information-rich narrative structure. There is good evidence we began to exploit conspecific trackways in our deep past, at first purely associatively, for safety and orienteering when foraging in vast featureless wetlands. Since our own old trackways were recognizable they were self-mirroring, triggering memories of what we had been up to in the past. Using them to find our way back to the band when temporarily lost or to re-find a resource-rich area discovered the day before enabled optimal foraging. Selection for daily reiteration of one's own old trackways therefore triggered the evolution of what is distinctive about human cognition: the autobiographical or narrative (episodic) faculty for imaginative self-projection. This faculty enabled us to glean useful social information from the stories "told" by other band members' old trackways, and created spin-off capacities for fast-track social learning. Resultant increases in socioecological complexity then created positive selective feedback loops for further entrenchment. Incrementally we became the ultra-social narrative-minded ape, capable of creating cumulative culture.

Keywords Episodic faculty · Mental time travel · Narrative self-projection · Simulation theory · Social complexity · Social learning · Theory of mind · Trackways reading

Trackways Reading: A Uniquely Human Cognitive Niche

Trackways are the patterns of indentations and other physical traces inadvertently left behind in suitable substrates (sand, soft clay, mud, volcanic ash, dust, new-fallen snow) and foliage (moss, grass, browsing marks on shrubbery) by the physical passage of all land-based animals.

Of all the lineages on this planet, including our great ape cousins, only ours has ever learnt to use this natural sign system to find unseen, unheard agents. All other terrestrial animals use scent trails and airborne odors. This article presents the hypothesis that, due to their very different properties from scent trails, entering the unique cognitive niche of trackways exploitation triggered evolution of the kind of cognition that enabled the fast-track social learning required for cumulative culture (Lewis and Laland 2012).

The article proceeds in four parts. First I provide my take on what is distinctive about human cognition by delineating fundamental aspects of our fast-track social learning capacities. I then introduce my paleoarchaeological model, which presents incontrovertible evidence that we began exploiting conspecific trackways at least 3.6 million years ago for safety and orienteering, and explains why only our ape lineage began to do so. The third part begins with an introductory lesson in trackways reading (TWR), partly because most of my readers have not read trackways, but mostly to point out the comparative simplicity of the cognition needed to glean the minimal information contained in scent trails. Three levels of TWR

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skill are then described, accompanied by archaeological evidence that might indicate when our lineage achieved them. Finally, since associative (here-and-now) rewards are needed for *any* form of cultural learning to occur, I show why trackways of conspecifics (not prey animals) must have triggered our entry into the TWR niche. The fourth part describes the incremental process whereby the simplest associative cognitive exploitation of our own trackways triggered selection for the narrative "elsewhere-and-when" cognition needed to read other band members' trackways (later applied to tracking other species). By "narrative cognition" I mean imagining being "in the body-and-mind" of absentee agents, including past and future selves. This enables mental time travel (Suddendorf and Corballis 2007) and mind-reading of (Tomasello et al. 2005) other agents in the present.

These capacities require self-aware autobiographical memory and prospection (Tulving 1985), which constitute the narrative (episodic)[1] faculty. I begin by explaining how this faculty for imaginative self-projection (Schacter and Addis 2007) makes the distinctly human capacity for fast-track social learning possible.

The Episodic Faculty and Fast-Track Social Learning

If the difference between human and non-human cognition is only "a matter of degree" (as Darwin conjectured), it has made a remarkable cultural difference. For instance, the first member of our species to make a footprint in the space dust on the moon's surface passed away just after I began writing this article. His name was Neil Armstrong, and the year he stepped out of the landing module on to the moon was 1969.

Like most people who are old enough to remember that day, I can quite clearly recall what I was doing when Armstrong's recorded voice came over the radio: "One small step for a man, one giant leap for mankind." I was with other first-year university students playing pool. Everyone in the pool room stopped and looked around at everyone else, then cheered and did various other things even complete strangers will do when they happen to be sharing the experience of a historic cultural moment.

Right now, nearly 45 years later, I can also remember I was lining up for a shot, but not whether I sank that ball, or who won the game. However I can picture the poolroom's layout and color, which of the two pool tables I was playing at, and the friend I was playing with. I can even remember thinking pool was a very apt game to be playing at that moment in time, with the pool balls scattered like "planets" over the green "space" of the velvet underneath them (embarrassing to remember now, but true).

All of the above is a description of an episodic memory (Tulving 1985), an excellent example of Thomas Suddendorf's "mental time travel" into the past of one's autobiographical self-narrative. The narrative (episodic) faculty also makes projection of the self into imagined "elsewhere-and-when" contexts possible in the "theatre of the mind" (Suddendorf and Corballis 2007). Let us return to our 1969 poolroom scenario for an example here.

In the midst of all that accumulated human culture and communication technology mentally linking us young students to such a momentous event on the moon, all the social cognitive behaviors we share with apes were being expressed: checking faces for emotional signals, gaze following, pro-social yelling noises, then grooming behaviors such as clapping others on the back, shaking hands, waving pool cues (like branches) in the air, drumming on tables (like chimpanzees pounding on hollow tree buttresses), and so on.

But on top of such associative "online" apelike social cognition, something very un-apelike was occurring. I bet every young man (few women played pool back then) in that pool room went mentally "off-line" as their involvement in group excitement dissipated, trying to imagine what it would have felt like "being in the body-and-mind" of either Neil Armstrong or his partner Buzz (Edwin) Aldrin when they were "moon-hopping" and looking back at their home planet.

Fast-Track Social Learning

This self-projecting adult cognition is linked to equally distinctive features of developmental cognition: pretend play, auto-rehearsal, and pedagogy. Preschool boys back then would have been playing "moon-landing games" and pretending (*what if*) to be astronauts, but some of them would have joined the air force when old enough, trying to realize that early dream. More importantly, with regard to the evolution of social learning, children are rehearsing practical (as well as social) skills when imitating absent older experts, no matter who they are pretending to be.

Most pretend games of hunter-gatherer (HG) children are imaginatively planned or scripted (unlike the play fighting, say, of other young animals), and are based on far more prosaic (*what is*) adult behaviors such as child care, hunting, building shelters in the surrounding culture (Hewlett and Lamb 2005). Of course young humans, like young chimpanzees, will also tag along with older children and adults whenever allowed, associatively trying to imitate them when they are plying their skills.

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[1] I will often override "(episodic)" with "narrative" this way throughout the article because narratives are made up of a series of episodes, and chimpanzees (and other animals like scrub jays for instance) are often said to possess some degree of "episodic-like" memory in the comparative psychology literature. Probably, but they certainly do not possess overwhelmingly narrative, "what-if" minds.

But here too, there is a major cognitive difference: “natural pedagogy” (Csibra and György 2011). Each step in a craft or skill is demonstrated for the younger learner by the older expert, who can autobiographically (episodically) remember those stages in his or her own learning history. The learner can then go away and auto-rehearse that “step,” using episodic memory to remember the “feel” and context of more successful action sequences and repeat them. Consider here how one remembers the physical “shape” and feeling of one’s best throws plus the weight and shape of the most suitable stones when learning how to skip them over water.

Collaborative pretend play, pedagogy, auto-rehearsal, and both over-imitation[2] and selective imitation (as in our “moon-landing games”) are tightly linked and developmentally canalized in our species. Many social learning theorists believe these are the uniquely human cognitive traits behind the high-fidelity transmission that made hominin cumulative culture possible (Lewis and Laland 2012), with their cognitive core being an extra capacity for exact imitation (see Csibra and György 2011; Nielsen 2012 for reviews).

I argue imitation is only part of the story; after all, apes are quite good imitators in certain contexts, yet learning simple foraging skills takes several years (over five for termite fishing; McGrew 2010). Consider here an accidental smashing of stone on stone that produced a flake with a usefully sharp cutting edge. Being able to episodically remember how making that particular blow felt, its angle and the type of stone, would make a reasonably accurate repetition possible. In effect, one is imitating the actions of a *past self*. The same goes for someone intentionally demonstrating a sequence of actions slowly so a novice can replicate them more easily.

Tulving (2005) thinks this autobiographical or *narrative* (episodic) sense of a self was *the* cognitive key to creating cooperative culture. I agree, mainly because of the above effects on social learning. As this faculty for fast-track social learning became more entrenched (and as our brains expanded), incrementally culture became more cumulative. But it all began with the capacity (plus motivation) to teach ourselves and others social and practical skills. It is the triggering of the evolution of this kind of “self-projecting” learning cognition my social trackways theory can explain.

As we shall discover in part three, narrative (episodic) self-projection, or imagining “being in the body-and-mind” of absent agents, including past and future selves, is the core cognitive capacity demanded by TWR (and socioecological applications of the information thereby gained) in its more sophisticated forms. Now for some paleoarchaeological orienteering to find out why only our ancestors started exploiting their own trackways.

Entering the TWR Niche: The Ardipithecans

The reason(s) why only our ape ancestors entered the TWR cognitive niche is not obvious, since all great apes are excellent visual pattern readers due to their exploitation of patchy resources. But adult chimpanzees take no notice of trackways, even when hunting conspecifics. I argue that this is because their lineage never possessed the adaptive suite of traits possessed by our recently discovered *Ardipithecus ramidus* ancestors.

Fossils from several *A. ramidus* individuals (including one nearly complete skeleton) robustly indicate these 4.4 mya hominins were:

(1) Facultatively bipedal, but with fully opposable big toes (still arboreal, nesting in trees at night, but definitely not knuckle walkers; Lovejoy et al. 2009).
(2) Omnivorous foragers (small molars, reduced canines; Lovejoy 2009) living in flood plains on the edge of wetlands within closed upland forests (WoldeGabriel et al. 2009), which indicates wetland foraging.
(3) Minimally sexually dimorphic in body size, with highly reduced non-honing canines of equal size in both sexes, indicating non-agonistic social breeding and provisioning with a shift towards monogamous pair-bonding (see Lovejoy 2009 for full discussion).
(4) Endowed with well-muscled lower limbs (they weighed around 50 kg), primitively short fingers, very pliable wrists; so they possessed an effective precision grip plus the weight needed for hard, accurate stone throwing and/or clubbing for defense and foraging (Lovejoy et al. 2009; White et al. 2009).

These fossils were found in what used to be a seasonal floodplain dominated by palms, bordering a large body of water. In fact, *all* early hominin sites were situated in and around wetlands and waterways (see Plummer 2004 for review). The idea of bipedal, omnivorous hominins habitually wading into shallow waterways to obtain shellfish and catfish (Stewart 1994) and edible-when-raw highly nutritious rhizomes of water lilies, papyrus, and cattails is no longer unorthodox (Verhaegen et al. 2002; Wrangham et al. 2009; Braun et al. 2010). Bonobos and gorillas indulge in bipedal wading when obtaining these rhizomes (Wrangham et al. 2009).

Lovejoy (2009) shows how the Ardipithecan evidence plus certain human hormonal and sexual traits robustly indicate a social-breeding/pair-bonding/provisioning lifeway this early in our lineage. Wading in waterways when foraging/provisioning is my contribution to his scenario. Of

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[2] Exact imitation of an older expert’s actions even when goal-relatedness of some of those actions is highly opaque.

course: taking helpless young out into waterways does not make sense. I think communal childcare and extractive provisioning does.

This means fission–fusion social navigation as part of the daily routine, and a far more collaborative, empathic social psychology than chimpanzees. Social breeders tend to be better social learners, and more culturally complex (Burkart and van Schaik 2010). But more importantly, as we shall soon discover, by around four million years ago we had become obligate bipeds.

For non-tree-nesting obligate bipeds getting one foot bogged in a mudhole or an ankle damaged by stepping on a loose river stone (especially when carrying a burden) can be extremely life threatening due to loss of mobility. Quadrupeds can still travel long distances on three good legs, as any hunter who has tracked a leg-wounded animal knows. Lost and/or lame chimpanzees can safely nest in the nearest suitable tree, but obligate bipedalism precludes that solution. So finding one's band every evening for the safety of group defense became crucial for survival.

Arboreal lifeways require visual/spatial rather than olfactory sense, so great apes have comparatively impoverished olfactory sensitivity. Becoming bipedal raises the nose well above ground level, and scent trails are extremely ephemeral in open watery environments. Nobody has explained why human olfactory sensitivity is much less than that of other apes (Lovejoy 2009). A wetlands foraging lifestyle could be one reason, but so could exploiting trackways rather than scent trails, on an "if you don't use it you lose it" basis.

To summarize the reasons why our post-Ardipithecan ancestors began to exploit their own trackways:

(1) Obligate bipedalism and no tree nesting makes where each foot is placed and finding one's band at nightfall crucial for survival.
(2) Their own footprints were ubiquitous and easy to perceive (unlike in jungles or dry savannah) on muddy patches of ground and sandy beaches, even in shallow water.
(3) The bipedal ability to see one's feet makes it easy to roughly replicate a leader's steps for safety and/or orienteering.
(4) Excellent visual pattern recognition combined with lack of olfactory sensitivity and the extra visual field created by perpetual bipedalism made large sections of trackways more salient *and* easy to recognize as belonging to individual band members.

I think giving up tree nesting and taking up social tracking through featureless head-high vegetation in endlessly fluctuating treeless waterways was therefore both possible *and* utterly necessary: the reasons were largely dietary in origin.

Figs are the staple diet of chimpanzees because individual fig trees fruit prolifically at idiosyncratic times during the tropical year. So chimpanzees can usually return to permanent tree nesting sites within their home ranges (Hernandez-Aguilar 2009). For more omnivorous post-Ardipithecans foraging in expanding treeless wetlands, giving up tree nesting was selected for because easily caught small fauna (shellfish say) quickly became rare in areas of concentrated foraging.

Their "un-chimpanzee-like" cooperative traits and physical capacities for group defense probably made this lineage-defining change possible. But I think associatively stepping in or near each other's footprints in very changeable and featureless watery environments for safety and orienteering was the other key to nomadic omnivorous foraging. In support of this idea, there is very robust evidence of obligate bipedalism, *and* this follow-the-leader mimetic tracking behavior 3.66 million years ago: the famous Laetoli Fossilized Footprints.

The "Tracking" Laetolians

The Laetolian Fossilized Footprints (see Fig. 1) were made by three of our ancestors stepping in 10 cm of volcanic ash

Fig. 1 Replica of some of the Laetoli Fossilized Footprints, clearly displaying juvenile's prints on left and prints of two adults on right, and showing the second adult is reiterating leader's prints. Bottom right dual print shows double attempt by the second adult. One can see their feet possessed arches and large humanoid big toes. [Photo by "Momotarou2012", Wikimedia Commons (http://creativecommons.org/licenses/by-sa/3.0)]

when crossing an open upland watershed now called Laetoli.

They reveal that (1) our "Laetolian" ancestors[3] already possessed extremely human-like feet, with our non-opposable big toes and heel-first, toe-off, straight-legged gait (Tuttle et al. 1990; Crompton et al. 2012); and (2) one adult stepped as exactly as possible in the footprints of a slightly larger adult. A juvenile was traveling in parallel on the left. Being a seasoned tracker I am sure it was held by the hand or around the shoulders by one of the adults; otherwise the trackways could not be so close and consistently parallel.

Reportedly the juvenile's prints looked fresher (Leakey and Harris 1987) than the dual trackway. The freshness of footprints is indicated by the definition or "crispness" of their edges, but of course the crispness of the second adult's prints cannot be discerned. However, since the adult with the smaller foot is more likely to be female, and a female is more likely to have a juvenile in tow, the juvenile's fresher prints indicate that she(?) was not at the male's(?) heels. Perhaps she was tracking him to try and find him. Mary Leakey also revealed that she and her colleagues tried stepping in each other's prints this exactly back at camp, and found it very difficult. And they didn't have a juvenile in tow *or* the local volcano threatening to spew more ash at any moment. In my own experience, stepping so exactly in a larger leader's prints for safety is very cognitively demanding if one is right at the leader's heels trying to keep the same pace, because a larger person usually has a longer gait. Besides, everyone has an idiosyncratic gait and angle of heel strike.

When *not* at someone's heels this exacting behavior still demands good mental concentration and top-down physical control, especially if one is attached to a smaller-gaited juvenile. It soon becomes cognitively stressful when maintained for long distances—and there is one badly misplaced attempt[4] towards the end of the 29-m dual trackway. Therefore our Laetolians possessed well-developed bodily awareness, and a more than ape-like capability for exact, intentional mimesis, an important trait for associative learning of practical skills.

If we add to these trackways the recent evidence of cut-marked bones,[5] dated at 3.4 mya, of an animal as large as a cow (McPherron et al. 2010), then at least one species of fairly smart hominins had evolved when these trackways were fossilized. My bet is they were smart enough for a female with a juvenile in tow to be tracking down her absentee partner *and* stepping exactly into his footprints for safety. But the bottom line is we can be sure our ancestors had begun to exploit their own trackways, for safety at the very least, by 3.6 Ma.

The Cognitive Topography of the TWR Niche

Consider the pictograph (Fig. 2) of footprints left behind in beach sand by a family of shelducks travelling from their nest in the dunes to the water's edge. On the left is depicted the first "image-ination" that would appear in the "theatre of the mind" (Suddendorf and Corballis 2007) of any human tracker who came upon these tracks and could recognize them as being those of a family of shelducks, with the adult male on the left (because of larger prints).

Immediately afterwards the end and beginning of the duck family's journey would be imagined (the end first because the prints "point" to the water). An image of a family of ducks feeding in the estuary would be followed by another of their nest in the dunes somewhere. Both images would be of other shelducks and their nests personally experienced in the past, of course. Here we can see how the narrative (episodic) faculty (plus semantic knowledge for context) is essential for gleaning trackways information.

A scent-trailing dog would only register shelduck(s), not easily captured young available. It could initially have followed their scent trail backwards before noticing it was getting weaker and turning in the right direction. If the ducks had walked through a puddle on their way, there

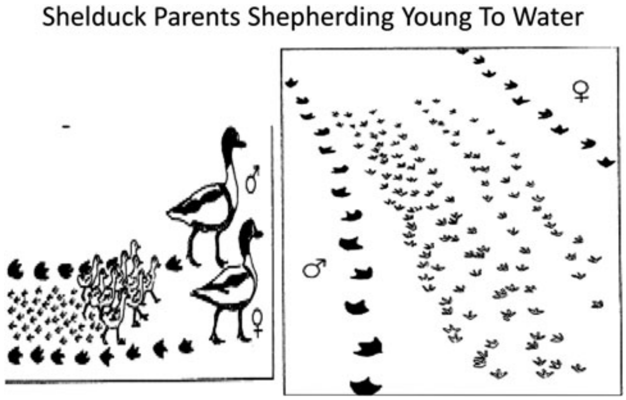

Fig. 2 A pictograph of footprints left by a family of shelducks traveling across beach sand from their nest in the dunes to the water (adapted from Lockley 1999). On the *left*, the first "image-ination" that would come to the mind of a human tracker is depicted

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[3] Too many theorists assume that these prints were made by contemporary *Australopithecus afarensis* found nearby. Others (who actually studied them in situ) are very adamant that they are too human-like to have been made by members of this australopithecine lineage. I agree with them for many reasons, too numerous to present here.

[4] This is where the relative freshness of her(?) footprints could perhaps be ascertained (see bottom dual prints Fig. 1).

[5] In the face of doubt as to whether these marks were made by stone tools, one of the cut marks has a tiny chip of stone firmly lodged in it.

would be no scent at all left behind by their feet. If they had journeyed an hour or so before, the scent would have already disappeared due to perpetual breezes in such open, watery environments.

A human tracker would routinely check the tracks nearest the water to see how fresh they were. Water still seeping into the print indentations means they have been made a minute or two before: the "authors" could be hiding in reeds just offshore. In very shallow water the adults' tracks would be perceivable for a fair way, but not their scent. If the breeze was blowing onshore the dog could smell the ducks out in the reeds, but not discern how far out they are. And airborne scents become directionally ambiguous over short distances in breezy conditions.

Our first lesson, then, is that trackways record narratives of what their authors were "up to" during the past. The second is that they contain much more information than scent trails. Gordon Hewes (1994) is the only other theorist who notes that trackways tell stories in a manner similar to languages:

> the total record left by some animal's tracks and other trailside signs within a normal time frame (such as the main part of a day) might be regarded as a kind of unintentional narrative, in which the tracker develops a profile of the kind of creature he is pursuing. The human tracker's cognitive achievement in forming such a "narrative" does not seem inferior to that required for transmittal of a comparably accurate verbal report … the process by which a nonhuman predator follows a scent track to its quarry is much simpler, depending mainly on pursuit of increasingly strong stimuli in the same mode. (p. 142).

However, the above level of TWR skill requires a narratively self-projective mind, capable of imagining "being in the body-and-mind" of absent agents. To understand why exploiting trackways in much simpler ways could trigger the evolution of this capacity, we must discuss basic differences between trackways and scent trails.

Trackways and Scent Trails: The Cognitive Gap

There are three major differences between the natural sign systems of trackways and scent trails. First, footprints are immediately and inexorably directional, oriented in space and time with respect to their authors' direction of travel. They will often have further information about a track maker's goals: an animal in flight leaves different footprint shapes and patterns to one sedately browsing. Second, they are immensely more durable than scent trails. Trackways can last for days or weeks instead of just a couple of hours or so, even in windy conditions or after a bit of rain, which will instantly erase scent trails.

Therefore, choosing which trackway of a targeted animal to follow is necessary and depends upon how "fresh" it is. The narrative tracking mind is always trying to discern when tracks were made. If a scent trail can be detected at all it is worth following, for its author cannot be far away. The scenting mind remains locked into here-and-now associative cognition, but the narratively tracking mind is under selection to read the time stamp on every trackway, and respond appropriately.

Third, because of their directionality and durability, trackways are *combinatorial*. Scent trails are not at all combinatorial because coming upon any fresher and therefore stronger scent trail instantly makes an older, weaker scent imperceptible.[6] Hence a police dog handler prefers to have an item of clothing of a targeted criminal on hand. Several trackways can overlay each other and still be visually discernible. Therefore they can provide a huge amount of information about past behaviors. For example, social trackways narratives reveal where and when two conspecifics met, whether they mated or fought with each other, whether they traveled together after that, and so on. This is important social information.

Combinations of tracks of different species can be used for time reckoning. The overlay of a trackway of a preferred diurnal prey animal by that of any nocturnal species (an insect, say) shows the targeted trackway was made the day before. Hence *all* trackways out there in the environment are grist for the tracker's cognitive mill. The tracking mind is thus perpetually enticed into imagining "being in other bodies-and-minds" in other contexts and times by all trackways encountered while going about the daily business. For a HG, reading trackway narratives is automatic, or "second nature."

The narratives told by trackways are combinatory and temporally ordered in the sense that:

(1) Complex narratives are comprised from a large but limited array of atomic elements: recognizable trackways of individuals or of species.
(2) The "meaning" of the complex narrative depends on the presence and arrangement of the individual atomic elements (as with words and sentences). By presence and arrangement I mean the following: Given (say) a meeting between trackways (x) and (y), if any footprint of (x) is overlying any footprint of (y) then we can know (x) was travelling behind (y) at that moment in time. If the trackways part and we decide to follow (x) because it appears to be fresher

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[6] As a young hunter I had a grouse-hunting (and duck-retrieving) dog for a companion. He had one "weakness": snowshoe hares. If he came upon a fresh scent of one of these while following an older grouse scent trail he could not resist following it. He never caught them, but it was fun for him (and frustrating for me).

> than (y), and yet later we meet (y) again, and this time (y) overlays (x), we know (x) and (y) were wandering along in the same general direction, but at their own speed, individually pausing to do various things.[7] Since we would already know what (x) had been up to we might then backtrack (y) to see what it had been doing (or if we are trying to capture one of them, following either track will do, for they are equally fresh).

Within these complex narratives, each trackway itself can provide an embedded narrative or "subplot." These "biographical" narratives are made up of a chain of episodes, depicted by sudden changes in footprint patterns, which describe temporal shifts in the relationships between an agent and its socioecological environment. This information is always worth having, for the daily routines of track makers indicate where they are likely to be in the future. On top of this, trackways of larger animals, especially humans, soon become individually recognizable. Scent trails are individually recognizable as well, but not nearly as durable (hence dogs obsessively urinate on scent posts) or information rich.

To sum up: unlike scent trails, trackways don't just record presence or absence. To the eyes and narrative mind of a modern tracker they very often reveal physical condition, sex, status in a group, preferred foraging and resting sites, emotional-mental state, and even the *character* of individual animals. There is not the space here to describe how one gains all this information from TWR (see Silberbauer 1981 and Liebenberg 1990 for good descriptions of the legendary tracking skills of the !Kung San).

In the next section I present an overall speculative view of the connection between increasing levels of TWR skill and the incremental evolution of narrative imagination.

Levels of TWR Cognition

Here I will borrow Liebenberg's (1990) three levels of TWR skill. He thinks erectines must have been pretty good trackers because they were endurance hunters. This kind of hunting only requires clubs for weaponry, but demands dedicated tracking of a specific prey animal (Liebenberg 2008). Like other evolutionary theorists, he has never discussed the cognitive relevance of *social* tracking.

Simple TWR: the opportunistic exploitation of recognizable trackways left behind by terrestrial preferred target species in easily read substrates such as wet sand and mud. Beyond the basic demand for individual and/or species recognition, simple TWR can be incrementally upgraded.

I think simple TWR development had three stages. The associative follow-the-leader rough reiteration of conspecific footprints[8] for bipedal safety is foundational. Next we have the non-associative exploitation of *old* footprints for personal safety *and* socioecological orienteering. Third, and crucially, we get the social marking aspect: human bipedal trackways are so easy to recognize San children know their mother's footprints from all others in the band by the age of four (Thomas 1963).

Opportunistic simple TWR would have been enough to follow conspecifics' old trackways in order to find them, follow one's own to refind foraging niches, or safely find one's way back to one's band. Improved orienteering also allows agents to expand their territories, for longer journeys are much safer. Hence expansion of open wetlands in savannahs during the Pliocene could have triggered selection for simple tracking.

The here-and-now desire to discover what absentee intimates are up to (a pair-bond partner, maybe) would have been a more powerful motivation for our ancestors to begin simple tracking than hunting other animals, since chimpanzees hunt adequately without using TWR. The trackways of dangerous local predators were probably the most salient before our ancestors had to start trying to obtain meat from larger mammals.

Simple TWR would have been good enough for finding large mammals and trying to force one or two of them (with a barrage of stones, say) to run into good miring spots in swamps, but systematic tracking would be much more useful for setting up such ambush tactics.

Systematic TWR: dedicated, intentional searching for a specific trackway through all terrains by also noting bent-over ground-covering foliage, dislodged pebbles and leaf litter, torn moss, scratches on rocks, blood spots if its author was wounded, and so on. It often requires imagining an agent traveling through the environment, because in some terrains (stony river beaches and bare rock outcrops) footprints are hard to find.

Simple tracking was upgraded in two ways: (1) being planned and sustained, rather than opportunistic; (2) increased sensitivity to a larger set of cues about the animal's passage through its environment. One must recognize the tracks of a *specific* animal after a short time, *and* imagine where it was heading when they disappear. This requires a good memory for normal animal behaviors: the systematic tracker is integrating natural history and local

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[7] Here we can see how trackways as natural signs could have been the cognitive template for creating gestural and then spoken languages in order to tell the stories we already had in mind. From this point of view, the words and sentences I am writing now could be seen as "thought prints."

[8] Polar bears and grizzlies will do this for ease of passage through deep soft snow; but they are doing this by feel, not by visual tracking for the sake of safety and orienteering.

geography via Dennett's intentional stance, projecting the tracker's own intentionality onto the target animal.

A theory of mind capacity that can imagine what mental state an agent is in (through interpretation of the visual patterns presented by its trackway) is also needed. Knowing whether an animal is frightened and therefore heading for its den or a thicket to hide in, or whether it is relaxed, just ambling about foraging is very useful. The better one is at narrative imagination, the quicker one is going to find the target animal's trackway again.

So developing systematic tracking skills was not possible without possessing the narrative (episodic) faculty to some degree. Systematic TWR can *always* be improved incrementally: the information gradient of TWR is very steep and open-ended, so selection for the necessary cognitive acuity would have been inexorable. I repeat: the erectines must have possessed good systematic TWR skill if they were endurance hunters (Liebenberg 2008).

If they were mainly ambush hunters (see Bunn and Pickering 2010), systematic tracking would still be necessary for gaining knowledge of the daily travels of the most suitable individuals (prime aged) of a targeted species in order to ambush them at the best time and place. Here we are approaching a more speculative, inductive kind of tracking.

Speculative TWR: systematically following a trackway for a while and then heading directly to where one inductively imagines the target animal might be, right now or by the time one gets there, given one's semantic knowledge of its routine behaviors and the surrounding terrain.

Systematic tracking will often take one upwind of a target animal as it changes its course. Speculating on where it is heading, leaving its trackway, and looping back downwind of it becomes necessary. It requires imagining the unseen track maker traveling to an unseen place to perform a routine behavior there. It also requires imagining one's future self approaching this unseen but narratively imagined place from downwind so one's own scent will not warn the wary prey. This inductive method of hunting requires possession of the narrative (episodic) faculty for self-projection into the future and the body-and-mind of another agent *plus* the neural capacity for storage of large amounts of semantic information.

The fully speculative level of TWR skill may not have been achieved before the beginning of language emergence and the final surge in encephalization between 700 and 300 kya (following Foley and Gamble 2009). There is good evidence of snaring techniques being used to capture small mammals around 450 kya in South Africa (Wadley 2010). Only a narrative mind can imagine exactly where an animal's head or foot is going to be placed in the future and then set a snare "just there." Being an experienced trapper I can testify that one also has to imagine "being in the mind" of the targeted animal: unnaturally arranged sites and baits make wild animals extremely wary.

Finally, TWR is *not* just useful for hunting: it is also important for predator avoidance, finding water, easy routes through rough terrain, and gathering (pig tracks lead to tubers). All !Kung San women are consummate trackers, often better than many of the men, and some join their husbands in the hunt for that reason (Biesele and Barclay 2001). All salient trackways information gleaned during the day by women gathering, juvenile males/old men setting snares, and mature male hunters is communally shared at nightfall when planning the next day's foraging (Silberbauer 1981; Liebenberg 1990).

The above point is important with regard to relating TWR to the evolution of modes of intentional communication. Another important consideration is selection for increases in encephalization for storage of socioecological knowledge gained by reading trackway narratives. Now we need to view the earliest evolution of TWR cognition from a larger perspective.

Overview of TWR Cognition

There are two major points to keep in mind. First, the information gradient of TWR is extremely open-ended and very steep. Any increase at all in the cognitive capacity to learn to read trackways would have increased social and ecological fitness throughout our lineage's post-TWR evolution. Second, it is very hard for a purely associative mind to even *begin* to exploit a system of natural signs with so much durability and information richness. The reward is very often significantly displaced in time (and therefore space). In contrast to visual hunting or scent trailing, there is no proxy reward: the sign does not get stronger, larger, or more salient as you approach the target.

Follow-the-leader reiteration of footprints has the associative reward of safety, and is easy to learn. It only required a capacity for prolonged imitation/emulation (still an important increase in associative learning skills). But what were the necessary associative rewards for (1) learning to reiterate *old* trackways and (2) beginning to *intentionally* follow them during our ancestors' entry into the TWR niche? Safety while orienteering is enough associative reward for opportunistically noticing and reiterating old conspecific trackways, but not for intentionally searching for them.

Crucially, there was another form of associative reward: psychological. Like scent signs, trackways of conspecifics became social markers, recognizable as belonging to absent social intimates (or to strangers). The associative reward for finding a social marker is the emotion triggered when it is recognized as belonging to an intimate other. The need for this emotional recognition reward means systematic TWR must have started in the social domain.

Social Trackways Reading

In the case of traditional South American Ache HGs the whole band is on the move through the jungle all day, with juveniles and old men breaking trail in front of the women and children gathering resources (and singing and chattering). Adult males are silently hunting in a distant half-circle roughly to the front and sides just out of sight of each other, thus defending the central group from predators and strangers (Hill and Hawkes 1983). The hunters communicate by single whistles to maintain equidistance (two means "help" or "found something"). The band regathers in well-known suitable clearings in the forest at nightfall, shouting to laggard or lost hunters after dark.

As I have previously indicated, for dietary reasons a similarly nomadic collaborative foraging style would make sense for our omnivorous ancestors in treeless wetlands full of more than head-high identical vegetation (using islands or peninsulas of higher ground for easily defended night-camps). It would also make habitual use of one's own and others' recent footprints for safety and navigation a daily routine (as well as vocalizing). The women and their cohorts could exploit the trackways the men in front of them made throughout the day, and use them to quickly join any male who vocally signaled finding a rich resource-gathering[9] site.

We moderns mimic/emulate footsteps without thinking about it when tramping on rough wilderness trails. If the *old* boot prints of the person(s) that traveled a muddy trail minutes, hours, or even several days before us show that neither of their feet got bogged down, one automatically steps in or near their prints. If the trail has been damaged (a wash-out perhaps), seeing that someone else has crossed the obstacle is very reassuring. If the trail crosses a large open river beach, one immediately starts searching for old boot prints in the sand, so as to more easily find the marked trail again on the other side.

This simple exploitation of old conspecific footprints for the still associative reward of orienteering would have immediately increased fitness in our ancestral wetlands-foraging niche. Here is the first of three fundamental aspects of my social tracking theory, for it allows for the very simplest (associatively rewarding and easily learnt) cognitive entrance into the TWR niche. The second is that such behavior requires fairly exact imitation/emulation of absentee track makers. The third is we must have acquired systematic TWR cognition through exploitation of our own footprint trails, not those of other animals.

This idea is amply supported by cognitive science. First, taking the same bodily posture one had during a past personal experience makes remembering that experience much quicker and easier. Second, it is much easier to *correctly* simulate (or "resonate" with) the actions and mental states of similar agents in similar positions and contexts (Shanton and Goldman 2010). So beginning to be able to imagine being one's past self (and therefore other band members) when physically reenacting old social trackways narratives is our best option for entrenchment of the narrative self-projection needed for systematic TWR skill.

The earliest tracking cognition, in a sense, consisted of pretending to be the absentee author of the footprints being stepped in, because social trackways were easily recognizable. This is low-level embodied simulation, the resonating physical mirroring of another agent's actions (Shanton and Goldman 2010). I speculate, in line with simulative low-level mind reading, that only by roughly stepping in or near (exactness would be too stressful) a target author's recognizable footprints could the earliest trackers keep him or her "in mind."

To scaffold this social mimetic tracking (besides associative recognition) we have *intimately knowing* the person being tracked. Seeing an intimate's footprint is emotionally like seeing that intimate "in the flesh." Finding a trusted band member's recent trackway (or your own) when you are lost is extremely reassuring. Conversely, discovering the trackway of a known bully, unknown stranger, or local predator becomes something like "seeing" them, engendering fear that motivates heading in the opposite direction to that trackway.

Now remember footprints, unlike scents, are always directional and will usually lead to the reward (or negatively point to an escape route from a future danger). Here is a "window" of a smooth, very incremental transition to high-level mentally simulative cognition (pretending to be "in the body-and-mind" of absent agents) needed for the beginnings of intentional, systematic TWR: not having to step in or very near someone's recognizable footprints in order to keep them in mind (when searching for their temporarily lost trackway, say).

This idea of embodied/mimetic triggering of non-associative social cognition becomes very important when one realizes that the old footprints habitually being used for orienteering and safety by our ancestors were very often their own. For then one is mimicking the earlier behaviors of *past selves*. The next section deals with our breakthrough to non-associative rewards being sufficient motivation for upgrading systematic TWR skills: being able to glean the social information contained in the stories told by one's own (and therefore others') old trackways.

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[9] Or that man could make an indicatory vocalization and leave behind a marker of some kind—another important idea with regard to the evolution of modes of conventional communication.

The Self-Mirroring Effect of One's Old Trackways

One can easily get lost on clouded-over days (no sun to reckon one's direction with) in flat, featureless watery environments covered in identical vegetation. When foraging in such environments all hunters[10] use their outgoing prints in reverse for safety *and* to find their way back to home base. It is called "backtracking." If you've been feeling lost because you cannot find your outgoing trackway for some reason (due to a sudden rise in water levels, perhaps) refinding that trackway will suddenly make you feel "found." For our ancestors this would have been a powerful psychological reward for learning to intentionally follow/backtrack their own old trackways.[11]

As per simulation theory, stepping in or near your own old footprints will trigger memories of your experience in making those footprints. One's own trackways narrative is made up of the episodic experiences of a past self: encounters with other band members, animal sightings (predators and prey), patches of berries, and other obstacles/rewards. These episodes will all be mirrored by sudden changes in the footprint patterns of one's old trackway. In addition, trackways are inexorably directional, appearing as if expressed by intentional or goal-directed agents.

The individual backtracking to the safety of the band is thus cognitively travelling into his or her personal past. This would be occurring daily with both one's own trackways and intimate, well-known band-member's footprints as well, for finding one's band before nightfall was imperative for non-tree-nesting bipedal apes. Following this, using one's old foraging trail to refind a narratively remembered resource-rich area discovered yesterday (just before nightfall, say) is using mental time travel to arrive at a goal in the future.

In sum then, habitually reiterating one's old steps for safety and orienteering is likely to continually trigger narrative memories made up of the *episodic* events that occurred when making them. And, quite simply, being bipedal means seeing your own feet making tracks points you into the future and from the immediate past.[12] Self-tracking hominins incrementally began to cognitively live with a sense of themselves (and therefore others, as per simulation theory) as being intentional agents travelling *narratively* through time.

Our ancestors thereby gained the capacity to intentionally search for and systematically read *all* old social trackways, motivated by the non-associative reward of information about past actions of conspecifics, strangers, and local predators. Social complexity would definitely be increased by the ability to gather this social information (a kind of "gossip"). As per Robin Dunbar's "social brain hypothesis," selection for further entrenchment of the narrative (episodic) faculty required for better social TWR skills was triggered.

Since this faculty enabled fast-track social learning of all other social and practical skills its incremental entrenchment also created powerful selective feedback loops driven by congruent increases in socioecological/technological complexity. Importantly, *any* advance in communicational efficiency would have directly and immediately amped up fast-track social learning.

Conclusion

I think the social trackways theory solves a long-standing puzzle: how and why did our ape lineage become so much smarter than others if it was triggered by an increase in social complexity? After all, our genetically closest ape cousins make tools, have cultural traditions, and are pretty good social learners (see Whiten and Erdal 2012 for a concise and recent comparative overview).

Whiten and Erdal think tracking prey animals was part of the socio-cognitive niche of early Homo HGs. I agree, but how was that cognitive TWR ability gained in the first place—in other words, how did our overwhelmingly associative ancestral ape mind become a narratively self-projecting elsewhere-and-when mind? A much earlier entry (via here-and-now embodied simulation) into the social TWR niche when our trackways became our social markers is the core idea of my thesis, and it solves the social complexity problem nicely.

Social complexity in our lineage then took the necessary (and often hypothesized) leap because of the unique "storytelling" characteristics of trackways as natural signs. We incrementally gained a distinctive kind of ultra-social cognition: a narrative (episodic) subjective awareness of ourselves as time travelers, able to imagine ourselves being in other places, bodies, minds, in other times; doing things in more effectual ways. Socioecological complexity amped up by fast-track social learning in all domains caused selection for neural expansion for storage of knowledge gleaned by our already narrative minds.

We became technological and social innovators, learning new "tricks" from each other (and the natural world) faster than any other species that ever existed on this planet. Why and how did we get to leave footprints on the moon? Through two million years of increasingly cumulative culture, of course, but we had imagined and then

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[10] They often leave markers (broken branches, blaze marks in tree bark) to make their backtracking easier and therefore quicker. This is very helpful when returning at nightfall.

[11] Studying one's own old and fresh trackways is the best way to learn how to read all other trackways.

[12] I owe this idea to Kim Sterelny (personal communication, March 2013): it is another embodied cognitive effect of obligate bipedalism.

physically rehearsed how to do it long beforehand. The social trackways theory firmly places an incrementally evolving snowball of fast-track social learning millions of years before the final avalanche of cumulative culture: sudden cultural "miracles" or genetic "leaps" are no longer required.

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