to be submitted to Behavioral and Brain Sciences, version 2/11/11)

A Tale of Challenge, Adventure and Mystery:

towards an agent-based unification of narrative and scientific models of behavior

Francis Heylighen
ECCO, Vrije Universiteit Brussel

Abstract: The scientific worldview is based on laws, which are supposed to be certain, objective, and independent of time and context. The narrative worldview found in literature, myth and religion, is based on stories, which relate the events experienced by a subject in a particular context with an uncertain outcome. This paper argues that the concept of "agent", supported by the theories of evolution, cybernetics and complex adaptive systems, allows us to reconcile scientific and narrative perspectives. An agent follows a course of action through its environment with the aim of maximizing its fitness. Navigation along that course combines the strategies of regulation, exploitation and exploration, but needs to cope with often-unforeseen challenges. These can be positive (affordances, goals), negative (disturbances, anti-goals) or neutral (diversions). The resulting sequence of challenges and actions can be conceptualized as an adventure. Thus, the agent appears to play the role of the hero in a tale of challenge and mystery that is very similar to the "monomyth", the basic storyline that underlies all myths and fairy tales according to Joseph Campbell [1949]. This narrative dynamics is driven forward in particular by the alternation between prospect (the ability to foresee challenges) and mystery (the possibility of achieving an as yet absent prospect), two aspects of the environment that are particularly attractive to agents. This dynamics generalizes the scientific notion of a deterministic trajectory by introducing a variable "horizon of knowability": the agent is never fully certain of its further course, but can navigate depending on its degree of prospect.

Introduction

People have always been searching for a conceptual framework that helps them to understand their place within the cosmos and that gives a meaning to their life. Perhaps the best term for such an encompassing philosophical system is a *worldview* [Aerts, Apostel et al., 1994]. When considering worldviews, we can distinguish two main "families" of contenders: mythical-religious, and scientific. The former are the oldest ones, dating back to the origins of humanity. The latter are relatively recent, having emerged with Enlightenment and the Industrial revolution. Due to its great

successes in prediction and application, the scientific worldview has become largely dominant in our modern age. Yet, it is still being challenged by various incarnations of the mythical-religious worldview, including Creationism, fundamentalist Islam, and New Age thinking.

Given the overwhelming amount of evidence for the scientific way of thinking, it may seem strange that its dominant position remains so precarious, and that the mythical-religious way of thinking remains so popular. In the present paper, I wish to explore the hypothesis that this is due not so much to the concrete content of the science, but to its form, that is, the way it is presented. Scientific knowledge is typically expressed in the form of *laws*, i.e. absolute, timeless rules that govern the behavior of all entities, thus allowing us to predict exactly what will happen to those entities in any circumstances. Mythical-religious knowledge, on the other hand, is typically expressed in the form of *stories*, which relate a sequence of events that happened to one or more protagonists. We immediately note three fundamental differences between these modes of knowledge (which Bruner [1986] calls "paradigmatic", respectively "narrative"): 1) stories follow the arrow of *time*, while laws are normally time-independent; 2) stories take place in a concrete, local *context* centered on one or more *subjects*, while laws attempt to be universally and objectively valid; 3) a good story always includes an element of mystery, suspense or surprise, i.e. *uncertainty* about the outcome, while laws try to maximally exclude uncertainty.

Science tries to minimize the impact of time, context, subject and uncertainty [Heylighen, 1999] because these reduce our powers of prediction, and therefore of control: theories that only work sometimes, at a particular time and place, and for a particular subject, are much less useful than theories that are accurate always and everywhere. This strength of scientific theories is also the weakness of mythical-religious narratives: while a story relating the trials and tribulations of a particular hero, god, or prophet may be inspiring, it is not clear what lessons to draw from it for another person living in a different context and epoch. This explains the proliferation of multiple, mutually contradictory interpretations of the same scripture.

But a story has another great advantage: it is psychologically much more compelling than a formal theory [Oatley, 1999a]. Empirical research has shown that information presented in the form of a story is assimilated more easily, has a greater emotional impact and motivational power, and is better remembered than the same information presented in a more abstract, context-independent manner [Heath & Heath, 2007]. This can be understood from the observation that evolution has shaped our brain as a tool to remember and draw lessons from personal experiences—not from abstract theories. Indeed, one of the most advanced mechanisms in the brain is *episodic memory* [Tulving, 2002], which functions to register "episodes", i.e. sequences of experienced events. We might say that stories have been shaped to directly enter episodic memory. When you listen to a good story you tend to empathize with the main characters, to imagine yourself to be in their place, and thus to relive their experiences inside your mind [Heath & Heath, 2007; Oatley, 1999a]. Because of this effect, educators and popularizers of science have learned long ago

that abstract knowledge is assimilated much more easily if it is presented in the form of a story—e.g. by relating anecdotes or biographical episodes about the theory's creators, or by recounting the historical sequence of steps through which a great scientific mystery was solved.

This power of story telling not only supports mythical thinking, religion and education; it is also the basis of literature, cinema, and many forms of entertainment. A multibillion-dollar industry has arisen in Hollywood and other places just to cater for the public's need to be entertained with compelling stories. Narrative is also the foundation on which the culture of the humanities is built. Half a century ago, the novelist-scientist C. P. Snow [1961] famously lamented the growing divide between the "two cultures", the scientific and the literary one. In spite of several attempts to bridge this gap [e.g. Prigogine & Stengers, 1984; Brockman, 1995], the separation remains as strong as ever.

The present paper proposes a new paradigm to bridge the gap between the two cultures. Thus, it may help us to unify the worldviews of science and those found in literature, myth and religion. This paradigm can be motivated by evolutionary psychology: if our brain has been shaped by natural selection to process events in the form of a story, then perhaps this is because life is indeed more story-like than law-like. Using the theories of evolutionary cybernetics [Turchin, 1977] and of complex adaptive systems [Holland, 1992; Miller, Page & LeBaron, 2007; Axelrod & Cohen, 1999] I will argue that real-world events have the same characteristics of time sequence, context-dependence, agent-centeredness and intrinsic uncertainty as stories. This 'narrative' dynamics can be summarized by the slogan "life is an adventure!" I will further show that while this new outlook by necessity limits the absolutist ambitions of traditional science, it by no means invalidates its results. On the contrary, the underlying paradigm of agents and their courses of action can be seen as an extension and strengthening of the scientific worldview, albeit one that is now truly compatible with narrative culture. To get there, I will first show where classical, Newtonian science has gone too far in its ambitions of reducing life to deterministic laws, and then how the new theories of complexity and evolution have opened up a fundamentally new perspective.

Beyond the Newtonian worldview

The clockwork universe

The modern scientific worldview is rooted in the mechanics of Newton, Laplace and their successors. The core metaphor of the Newtonian worldview is *the world as a clockwork mechanism*: a complicated array of gears and wheels working together in perfect unison, so that all their movements are regular, clearly observable and accurately predictable. This seemed the perfect model for the movement of the planets around the sun, which is indeed extremely regular and predictable. This was already demonstrated in ancient Greece by the Antikythera mechanism (2nd century BC), a

complicated clockwork that functioned like an analog computer. It allowed users to accurately forecast the positions of the astral bodies by turning a crank that would move the mechanism forward to any date in the future [Freeth, 2009].

Newton's equations allowed scientists to capture this motion in a mathematical formalism that was applicable not just to the astral bodies, but in principle to any material object. It therefore was not such a big leap of the imagination for Laplace, a century after Newton, to conceive of a demon that would be able to observe the position and velocity of all material objects in the universe, and use this information together with Newton's laws to predict the future evolution of the universe in every detail.

Laplace's demon constitutes an immensely influential thought experiment. It led both to a general philosophy of determinism and to the disappearance of God from the scientific worldview (Laplace is famously quoted as observing that he had "no need for this hypothesis"). Indeed, if the laws of motion together with the present state of the universe completely specify any future (as well as past) states, then there is no possibility for God, human or animal to intervene in the course of things, and all events, future or past, are already determined. What appears to be evolution or change is merely the translation of material objects along pre-existing trajectories determined by the laws of motion [Heylighen, 1990]. Time then is nothing more than a coordinate used to label the successive positions along those fixed trajectories—playing a role similar to the position of the crank in the Antikythera clockwork.

Since everything is a priori determined, all notions of uncertainty, freedom, surprise, novelty, creativity, and evolution become pointless. The same happens to all notions that imply will, intention, goal-directedness, purpose or meaning: since it is anyway already determined beforehand whether you will reach a particular goal or not, it becomes pointless to reason in terms of striving, trying, or achieving. The notion of goal or purpose in particular makes no sense in the Newtonian worldview: since effects are already fully determined by their (past) cause, there is no room for any (future) goal state to influence what happens here and now. This leads to the often-heard criticism that science paints a bleak, mechanistic picture of life, which leaves no space for meaning, values or ethics. Unfortunately, that criticism is often misinterpreted to imply that we need to go back to some supernatural, mystical or religious explanations.

Limitation Principles

Present-day science has long invalidated the basic tenets of the Newtonian/Laplacean worldview. Most obviously, the twentieth century has produced a raft of "limitation principles" proving that complete, certain knowledge is impossible—not just in practice, but in principle [Barrow, 1998]. The most famous ones are:

1) the *Heisenberg uncertainty principle*, which shows that the observable properties of particles are intrinsically indeterminate,

2) the *theorem of Gödel*, which shows that even in pure mathematics we will never be able to establish with certainty the truth or falsity of certain propositions,
3) the existence of *deterministic chaos*, more colloquially known as the "butterfly effect", which notes that many physical systems, even when they are in principle deterministic, are so sensitive to unobservably small fluctuations in their initial conditions that we will never be able to predict their future evolution [Prigogine & Stengers, 1984].

As an illustration that this list of limitations on predictability is merely the top of an iceberg, let me just mention two lesser-known limitations:

4) the *halting problem*, which shows that even in the completely deterministic domain of computer programs, we can in general not predict whether a particular program will come to some conclusion or continue to run indefinitely;
5) the *finiteness of the speed of light*, which implies that in whatever way we get information about remote parts of the universe this information will be inaccurate when we get it, because the situation will have changed in the time that the information needed to travel to us.

The conclusion is that the demon of Laplace will not only be unable to get all the information it needs, but unable to calculate future trajectories based on that information, partly because of intrinsic limitations on computability, partly because the trajectories are fundamentally indeterminate and chaotic.

This means that unpredictability has to be a part of the scientific worldview. Prigogine [1997] has explored some of the philosophical implications of this "end of certainty", arguing that it opens the way to reconnect science with the humanities by allowing for the appearance of novelty [Prigogine & Stengers, 1984]. However, merely acknowledging uncertainty's role in science is hardly sufficient to unify scientific and narrative modes of thought.

Complex Adaptive Systems

More important even than the theoretical limitations on predictability are the practical constraints [Gigerenzer & Goldstein, 1996]. Complete, accurate and reliable predictions are in practice only possible for simple, isolated, "clockwork-like" systems, like planets rotating around the sun, balls running down an inclined plane, or strictly engineered systems such as cars and televisions (and even those break down at moments they are not supposed to). Most systems of real-world importance, such as organisms, organizations, markets, brains, ecosystems, or the weather, are extremely complex and open to a variety of perturbations coming from outside the system under observation. This makes it intrinsically impossible to establish the initial conditions of the system with any degree of accuracy. Moreover, because they are non-linear, they are particularly prone to various "butterfly effects" that magnify tiny errors or fluctuations in these initial conditions [Heylighen, 2009].

These observations have given rise to a novel paradigm for modeling complex phenomena, under the label of "multi-agent systems/simulations" (MAS) [Wooldridge, 2002; Miller, Page & LeBaron, 2007]. Instead of producing an exhaustive mathematical description of the system in question, the MAS approach starts by identifying the most active components of the system, the so-called *agents*. In an organization or society, the agents are individual people, in an ecosystem they are organisms, in an organism they are cells, in a market they are firms, etc. Agents are assumed to be *goal-directed*: they try to maximize their "utility", "benefit" or "fitness". However, because of the complexity of the system and their intrinsic cognitive limitations, agents are by definition *uncertain*: they only have local knowledge, and cannot foresee the global or long-term effects of their actions. Agents act on their environment and on each other according to certain rules, determined by their goals and knowledge. Formalizing these rules makes it possible to write a computer program that simulates the interaction between the different agents, and its further evolution. While such MAS in general cannot make reliable quantitative predictions, they often succeed in producing amazingly accurate qualitative predictions and, more importantly, explanations.

While agent-based modeling has become a very popular, flexible and useful method, its conceptual foundations remain vague. The paradigm of "complex adaptive systems" (CAS) [Holland, 1992; Miller, Page & LeBaron, 2007] provides a first justification for why systems of interacting agents are so fundamental. It takes its inspiration from the biological theories of evolution and ecosystems, together with social science theories of markets and societies. In this paper, I wish to take the CAS paradigm one step further, by analyzing the concept of agent more deeply, with a focus on the agent's interactions with its complex and uncertain environment.

The Behavioral Sciences

The disciplines that study human behavior tend to be divided in their choice for either scientific or narrative perspectives. The humanities have generally opted for a narrative perspective—as is most obvious in history and literary theory. Economics and academic psychology, on the other hand, like to position themselves squarely into the scientific camp, driven in part by what has been called "physics envy", i.e. the desire for a fully mathematical, deterministic theory based on precise laws of behavior. However, this desire has been largely frustrated up to now, as human behavior appears much too complex to be reduced to deterministic models. Sociology, psychiatry, philosophy, and anthropology mix both perspectives, depending on the problems addressed or the traditions within a particular school of thought.

The difference between the corresponding methodologies has perhaps been formulated most sharply as the *idiographic – nomothetic* distinction [Cone, 1986]. Nomothetic investigation aims at the formulation of general laws that describe the behavior of broad classes of individuals. Idiographic studies focus on the particular characteristics of a single individual. Although a nomothetic theory may seem

preferable because it can be applied to an unlimited number of cases, proponents of the idiographic approach argue that each case is unique, and therefore nomothetic generalizations merely succeed in capturing superficial similarities between cases while neglecting their rich, individual essence. Perhaps the most compelling idiographic approach for studying individual behavior is biography [De Waele & Harré, 1979], i.e. a narrative reconstructing a particular person's *life story* [McAdams, 1999], as this may provide an insight into how or why that person came to perform certain unique actions (e.g. commit a crime, or make a scientific discovery).

The present paper does not propose an answer to the difficult question of when a nomothetic approach is preferable to an idiographic one, or vice versa. Instead, it proposes a new conceptual framework that to some degree unifies the core ideas of scientific and narrative perspectives. It achieves this by generalizing the idiographic notion of a *life story* with the help of the nomothetic notion of an *agent* whose behavior is governed by the principles of evolution, cybernetics and complex adaptive systems. This will lead us to replace the Newtonian metaphor of "behavior as the movement of a clockwork mechanism" by the novel metaphor of "life as an adventure".

An ontology of action and adventure

Striving for fitness

Biology has long ago come to the conclusion that all living beings are the product of evolution. This means that they must be sufficiently fit not to be eliminated by natural selection. *Fitness* here refers to the general ability to survive, grow and reproduce within a given environment, by making productive use of the resources available in that environment, while effectively evading its dangers. Since a potentially unlimited number of organisms compete for a finite amount of resources (nutrients, energy, water, shelter, etc.), in general only the small fraction that is best adapted will survive. Through this continuing selective pressure, evolution has programmed living beings to maximize fitness: those that would stop trying to improve their fitness relative to the others would very quickly lose the competition with those others, and be eliminated from the scene. Therefore, we may assume that all living agents are driven by fitness as their ultimate, underlying value.

Note that organisms do not explicitly aim at the abstract notion of fitness: they target a variety of more concrete goals and values that function as (not always perfect) proxies for fitness. For example, we eat not in order to gather the resources optimal for survival and reproduction, but in order to satisfy our hunger. The fact that the two goals are not always consonant is illustrated by the phenomenon of obesity, a situation in which people eat so much that it actually reduces their fitness. When we speak about people, or other higher organisms, we may in practice replace the abstract concept of fitness by the somewhat more intuitive notions of *benefit*, *happiness*, or

what economists call "*utility*". Indeed, it can be argued that evolution has shaped our instincts and feelings in such a way that the things that make us satisfied are in essence the things that contribute to our fitness [Heylighen & Bernheim, 2000; Veenhoven, 1997]—although the example of overeating reminds us that the correspondence between short-term pleasure and long-term benefit is not always perfect.

Striving for fitness implies striving for access to resources. Different types of organisms will typically need different resources in different circumstances. Therefore, while they all try to maximize the universal value of fitness, in practice they will achieve this via different local goals and values. For example, carnivores strive for meat, herbivores for plant material, and plants for sunlight and nutrients. These agent-dependent values will be realized via even more local goals. For example, while a lion in general strives for meat, in a particular condition it may aim to catch a zebra or to eat from the carcass of a wildebeest, depending on the local context. People, as the most complex organisms, will try to achieve the resources they need via a very diverse array of local strategies, which may include hunting, gathering, farming, trading, producing goods, offering services, gathering knowledge, striving for political power, and even prostituting oneself.

Most generally, such a strategy may be called a *course of action*. It can be defined as the series of actions that an agent can be expected to perform in order to increase its fitness, while taking into account both the local circumstances and more remote goals and values.

Regulation

Given that evolution implies goal-directed activity, we now need to study how goals can be achieved. This is the subject matter of *cybernetics*, the science of governance, communication and control [Ashby, 1964; Heylighen & Joslyn, 2001]. Cybernetics has resolved the old conundrum of how to model purposive action without contradicting causality by introducing circular causality [Rosenblueth, Wiener & Bigelow, 1943; Heylighen & Joslyn, 2001]. Goal-directed behavior is understood as a process of control or *regulation* [Powers, 1973; Carver & Scheier, 2001]. It consists of the following components:

1) perception, i.e. the process whereby an agent gathers information about its situation;
2) evaluation, whereby the agent compares the perceived situation with the desired situation, i.e. its goal;
3) decision, whereby the agent chooses the action or strategy most likely to minimize the difference between the perceived situation and the goal;
4) action, whereby the agent intervenes in the situation;
5) feedback, whereby the agent re-assesses the new situation as changed by the action and by possible outside events.

If the action was successful, the difference between perceived situation and goal will have diminished. Therefore, the feedback is negative: it *reduces* deviations from the goal state. Phase (5) (feedback) is equal to phase (1) (perception) of a new feedback loop, intended to reduce the remaining differences between situation and goal.

In this way, the agent will constantly be monitoring the result of its actions, intervening whenever necessary to come closer to, or remain at, its goal state. Further intervention is necessary when the previous action was insufficient or unsuccessful. Failure to achieve the intended result may be due either to an error made by the agent (e.g. miscalculating the effect of the action, or executing it clumsily), or by a hindrance originating in the environment (e.g. appearance of an obstacle, unforeseen change in the conditions). All these phenomena that obstruct or endanger the achievement of the goal can be subsumed under the generic term *disturbance*. The beauty of the cybernetic regulation loop is that the nature of the disturbance does not really matter: whatever the origin of the deviation from the desired course, it will merely trigger another corrective action. As long as actions are more likely to decrease the deviation than to increase it, a sufficiently long series of actions is bound to dependably advance the agent towards its goal.

This feedback loop is a robust method for dealing with uncertainty. The environment of an agent is normally complex, dynamic and to an important degree unpredictable. This means that the agent will sooner or later be confronted with a *problem*, i.e. an unintended deviation from its goal. But whether this disturbance was foreseen or not does not matter for the mechanism of regulation: the only thing that counts is the direction of the deviation, since this determines the corrective action. For example, when you drive a car, you will repeatedly need to brake, turn to the left, or turn to the right in order to avoid other vehicles or obstacles that appear on your intended path. Knowing where and when an obstacle will appear is only marginally useful: you will anyway have to take corrective action once you get there.

Challenges, Directions and Diversions

In spite of its flexibility and universality [Powers, 1973], the paradigm of regulation is still too restricted to capture the full dynamics of behavior. The notion of regulation is intrinsically *conservative*: it assumes that there is a single ideal state—the goal—and that anything causing a deviation from that state constitutes a disturbance that must be suppressed. In practice, the world is more complex and variable than implied by this simple scheme. At best, goals are temporary and contingent on the circumstances. Ultimately, they are all subordinated to the abstract and unlimited drive for fitness increase. Successfully striving for fitness is as much a matter of choosing appropriate goals as of effectively achieving these goals. For example, the lion that failed to catch a zebra would do better to eat from the carcass of a wildebeest it just stumbled upon than to persevere in its unsuccessful attempts at killing a far-away prey.

This means that we need to introduce several generalizations and extensions to the cybernetic paradigm of regulation. First, the positive notion of goal is readily

extended to its negative complement of *anti-goal* [Carver & Scheier, 2001]. This is a state that the agent wishes to distance itself from as much as possible, because it threatens to reduce its fitness. For example, for a zebra wandering across the savannah, a watering hole may be a goal, but a group of lions an anti-goal. Evading anti-goals is achieved via a deviation-increasing positive feedback loop, based on the same regulatory components of perception, evaluation, decision and action, but where the action is now chosen to increase (rather than decrease) the deviation from the anti-goal.

The negative notion of disturbance can be similarly complemented by the positive notion of *affordance* [Gibson, 1977; Heylighen & Vidal, 2008]. An affordance is a phenomenon that enables or affords achieving some benefit. It can variously appear as a tool (e.g. a telephone, a stick), a resource (e.g. money, food, energy), or an opportunity (e.g. encounter with someone who can help, a clearing up of the weather). An affordance allows you to increase your fitness. But whether you really get that benefit will depend on your ability to recognize and exploit the affordance, which requires a change in your course of action.

Both affordances and disturbances are special cases of the more general notion of *diversion*. A diversion can be defined as anything that makes an agent deviate from its present course of action (see Fig. 1). Such diversion may be positive (affordance), negative (disturbance), but can also be in between, i.e. neutral (general diversion). A diversion is positive when it makes it easier than expected to achieve benefit. It is negative when it makes things more difficult. It is neutral when it simply changes the situation in such a way that you need to set out a new course of action, which is neither easier nor more difficult than the previous one. For example, encountering a friend is an affordance; encountering a foe is a disturbance; encountering a stranger is an initially neutral diversion—which may turn out to be positive or negative depending on how the stranger reacts to your actions.

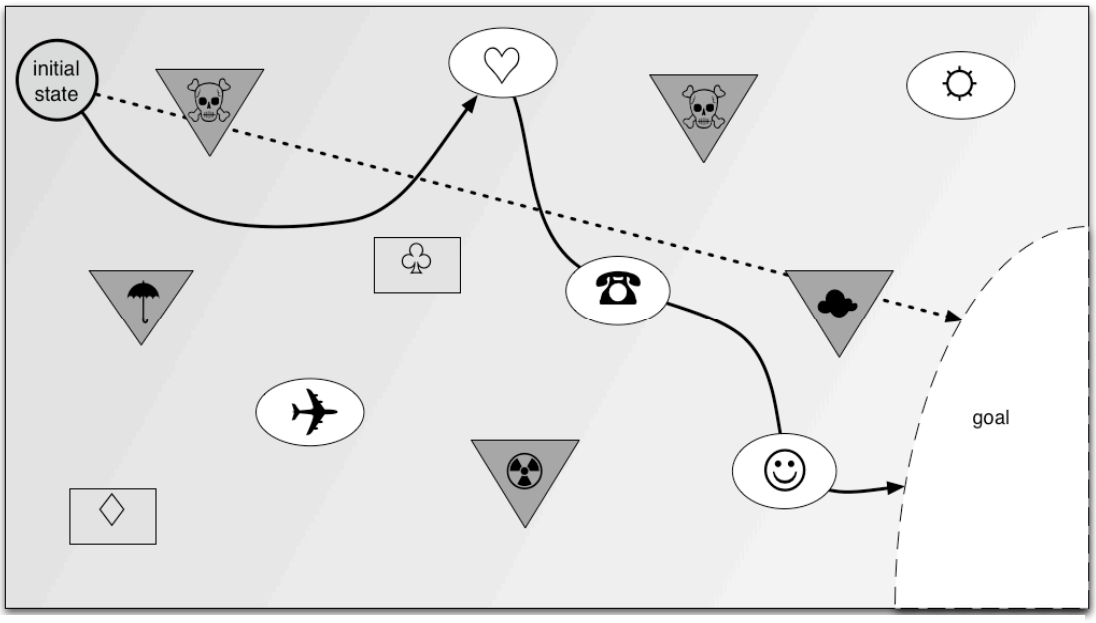

Figure 1: Graphical representation of a course of action.

A course of action is the path followed by an agent through its search space, here shown from its present state to its (provisional) goal. The dotted arrow represents the course that it would follow under the sole *direction* of the goal. The full arrow represents its actual "meandering" course, affected by the *diversions* encountered on the way: disturbances (dark grey triangles) to be avoided, affordances (white ellipses) to be exploited, and neutral diversions (light grey rectangles) that merely shift the course in a different direction.

As a last step in our broadening of the paradigm of regulation, we need to note that there is no absolute difference between a goal and an affordance, or between an anti-goal and a disturbance. A goal is merely a "planned" or "intended" way to achieve benefit, while an affordance is a serendipitous one. Similarly, an anti-goal is a problem that you intend to steer clear off, while a disturbance is one that catches you unprepared. The difference is one of targeting: actions can be directed by far-away targets (goals, anti-goals), or be diverted by what happens here and now (disturbances and affordances). The former actions may be called *proactive*, since they function in anticipation of an as yet still remote situation; the latter *reactive*, since they respond to the situation after it has been experienced.

But the difference is not absolute, because the degree of targeting is variable: agents only have a limited degree of prospect, and thus only a partial and unreliable view of goals and anti-goals. Therefore, the direction of their actions has to remain flexible and approximate, so as to allow immediate corrections to the course of action when additional information comes in. For example, as you draw nearer to what looks like a watering hole, you may start to discern a troop of lions drinking there, prompting you to shift the direction of your movement towards the stretch of water farthest away from the lions.

The different situational influences on the course of action can be grouped under a general concept that encompasses all the situations we discussed. A *challenge*

is *a phenomenon that invites action from an agent*. Action may be elicited because it promises a gain of fitness if it is performed (positive challenge), because it threatens with a loss of fitness if it is not performed (negative challenge), or because of some combination of the two. Challenges can be classified according to the dimensions of *valence* (positive-negative) and of *prospect* (proactive-reactive). Prospected (i.e. anticipated but as yet remote) challenges guide or orient the agent's long-term course of action, and may therefore be called *directions*. Goals direct the course *towards* something, anti-goals *away from* something. Challenges that interrupt or deflect this directed movement are then what we called *diversions*. These two dimensions lead to a 2 x 2 classification of challenges as depicted in Table 1.

\valence prospect	**Positive**	**Negative**
Directions	Goals	Anti-goals
Diversions	Affordances	Disturbances

Note that the absolute value of the valence dimension determines the impact of a challenge: high-valence challenges promise a large fitness gain (e.g. an opportunity to mate and thus produce offspring) or threaten with a large fitness loss (e.g. a mortal danger). They are therefore intrinsically more compelling than challenges with lower valence—i.e. more likely to elicit action. A final dimension worth mentioning is the difficulty of a challenge. Easy challenges require little action, effort, or resources to be tackled and therefore are very likely to result in success, while difficult challenges may demand more resources than the agent is able to muster. Even when the challenge is clearly foreseen, its degree of difficulty creates uncertainty about the final outcome. While agents are intrinsically free to either address a challenge or to ignore it and focus on a different one, their choice of which challenge to address will normally depend on these dimensions: the higher the valence, and the lower the difficulty of a challenge, the more likely that the agent will take it on.

In conclusion, challenges can be seen as the most fundamental determinants of action: they both direct and divert an agent's course of action, depending on their relative degrees of valence, prospect and difficulty.

Exploration and Exploitation

In general, negative challenges are to be evaded, positive ones are to be exploited, and as yet undetermined ones are to be investigated or explored. This leads us to another generalization of the cybernetic notion of regulation: regulation can only suppress diversions (or in the best case, when they are positive, allow them), and is therefore intrinsically conservative. But to maximally benefit from affordances, the agent needs to find such affordances. This requires an intervention that is directed not at suppressing diversions, but in a sense at precipitating them—in the hope that one of

them turns out to be positive. This process of eliciting diversions may be called *exploration*. Exploration means venturing into the unknown with the intention of discovering new information, resources, opportunities, or—most generally—affordances. Exploration is the default mode of navigation when there is a lack of compelling directions. It implies a course of action that is moving away from what is foreseeable (the prospect), and towards what is not (what we will later call "mystery"). The main rationale for moving away from the known is that the valences (potential goals) it offers are less attractive than the valences (affordances) that might be expected from the unknown. In other words, however rich or poor the known valences may be, the agent will tend to leave them behind if it suspects that it "can do better" elsewhere.

Examples of exploration are animals foraging for food [Kramer & Weary, 1991], plants releasing their seeds in the hope that some of them land on fertile ground, children playing, scientists or artists performing experiments, and—of course—travelers exploring new territories. In our highly regulated industrial or agricultural societies exploration may seem like a rather unusual activity reserved for researchers, inventors or adventurers. However, it is actually the default type of behavior for most animals and hunter-gatherers. Indeed, in natural circumstances food is typically scarce and its location uncertain, and therefore on-going exploration is needed to find it. If food were predictably present at a certain location, a growing number of competing organisms would gather there to consume it, until the supply would be exhausted. This would force them all to find a new supply—one that is preferably as yet unknown to their competitors. That is why it is advantageous for agents to be as diverse and unpredictable as possible in their exploration strategies.

While regulation is the straightforward method to deal with negative challenges, positive challenges call for either exploration or exploitation. *Exploitation* means making use of already known affordances in order to maximally extract benefit. *Exploration* means searching for hitherto unknown affordances. Neither approach is sufficient on its own. Exploitation is in general more efficient and less risky than exploration, since the agent does not lose time, energy or possibly life in failed ventures. Yet, as we noted, exploited resources tend to get exhausted and need to be renewed. Moreover, newly discovered resources may turn out to be much richer than the ones already known. Therefore, agents that stick to the known will sooner or later be outcompeted by those that dare to look further, and thus discover more powerful affordances.

The best strategy therefore is a mix of exploitation and exploration. The difficult choice about how much effort to invest in each alternative is known as the *exploitation-exploration trade-off* [March, 1991; Cohen et al., 2007]. While there does not seem to be an optimal strategy for making this decision, a general rule-of-thumb could be the following: the more variable or unstable the affordances—i.e. the higher the probability that known affordances would vanish or that novel affordances would appear—, the more exploration is likely to be beneficial.

A classic example of this dilemma can be found in ant foraging strategies [Sumter & Beekman, 2003]: an individual ant has the choice either to follow a pheromone trail left by other ants that leads to a known food source, or to deviate from the trail and possibly discover a new source. If ants would always follow existing trails, food sources would eventually get exhausted and the ants would die of hunger. If ants would never stick to the trail, on the other hand, they would each time again spend most of their time wandering around aimlessly until they happen to run into a food source, so that on average they would only recover a fraction of the food that they would get with a more exploitative strategy. In practice, ants follow the trails most of the time (exploitation), but with a small probability of deviating from the trail so that they could potentially discover a new source (exploration). The value of this deviation parameter has probably been set by evolution so as to optimize the long-term fitness of the ant colony.

An agent trying to maximize its fitness will therefore need to apply a judicious combination of regulation (moving away from known anti-goals and disturbances), exploitation (moving towards known goals and affordances) and exploration (moving into the unknown). Together, these steering mechanisms determine the process of *navigation*. Like the great navigators in the past, navigation requires correcting any unfavorable deviations from the present course of action (regulation), while at the same time further setting out or adjusting this course of action so as to most efficiently exploit observed affordances, while still maximizing the chances of discovering new affordances (exploration). The eventual trajectory of a navigator is essentially unpredictable: while its initial aim or direction may be clear, positive and negative diversions will upset the smooth advance and are likely to create deviations so large that the end point may be completely different from the intended one. For example, while Columbus aimed to reach India via a Western route, he ended up discovering the unknown and much larger continent of America.

Life as an Adventure

The appearance of diversions, in the sense of unforeseen challenges that make the agent deviate from its course, is an inevitable result of the fundamental unpredictability of the universe. But these diversions are not random: most of them are very meaningful to the agent, in the sense that they signal dangers or opportunities; obstacles or resources; disturbances or affordances. The information they provide helps the agent to correct its course of action, adding to its overall knowledge of its surroundings. Yet, in an infinitely extended universe the unknown will always remain larger than the known. Moreover, extending the known will at the same time extend its frontiers with the unknown, and therefore the opportunities for further exploration. Researchers will be the first to admit that the more they get to know about a domain, the more they become aware of all the things they do not know yet.

A good paradigm for this directed but meandering course of action, driven by challenges while mixing the expected with the unexpected, is the concept of *adventure*. The Latin root of this word, the verb *advenire*, means "to come about, to happen to (someone)". This refers to the (in general unpredictable) challenges that an agent encounters on its journey. From this, the word got its modern meaning of a succession of in part unintended (and therefore potentially dangerous) encounters. According to the American Oxford Dictionary, "to adventure" means "to engage in hazardous and exciting activity, esp. the exploration of unknown territory". More generally, an adventure may be defined as a series of challenges—partly intended (directions), partly unintended (diversions)—through which an agents needs to steer an effective course of action. The valence, difficulty and unpredictability of the challenges confront the agent with danger, opportunity and surprise, while producing exciting experiences. This includes the fundamental concepts of *action*, risk or *uncertainty*, and excitement or *emotion*.

Emotion is the only concept that we have not yet discussed in our ontology of action. An emotion can be seen as a state of "action readiness" [Frijda et al., 1989; Frijda, 2007], in which mental and physical resources, such as muscular tension, arousal and attention, are mobilized in order to deal with a challenge. According to cognitive theories of emotion [Simon, 1967; Oatley, 1999b], excitement or arousal is typically produced by a deviation from the expected course, or what I have called a "diversion". Therefore, an adventure, as an experience that includes surprising deviations from the course set out by the agent, will necessarily bring about emotional arousal. But arousal can also be triggered by situations with high valence: passion, attraction, fear, and hate are also forms of "readiness", but now for known, predictable challenges, i.e. what we called "directions". In general, emotion can be understood as a mechanism for *mobilizing* the right amount and type of internal resources that an agent needs to deal with the challenges it encounters, so that it can move along an adaptive course of action. ("Emotion" and "mobilize" have the same Latin root referring to movement). For example, an anti-goal may produce the emotion of fear, while a challenge with high valence but even higher difficulty may induce the emotion of resignation. The "stronger" (in terms of valence, difficulty and unexpectedness) the challenge, the more intense the emotion.

This brings us to a final characteristic difference between the scientific and narrative cultures: the former insists on dispassionate, rational analysis; the latter is most interested in subjective, emotional experiences. While there is definitely a great value in rational thought, the fact that evolution has given us such a sophisticated sense of emotion should remind us that feelings and intuitions are often more effective than logic in quickly coming to grips with a challenging and especially unexpected situation. Modern science has started studying these inevitable deviations from rational thinking under the label of "bounded rationality" [Simon, 1982; Gigerenzer & Goldstein, 1996; Kahneman, 2003].

In conclusion, building further on a variety of new scientific theories and insights, I propose to replace the fundamental metaphor "*the world is a clockwork*

mechanism", by the metaphor "*life is an adventure*". This metaphor, I believe, provides a more accurate picture of behavior as a sequence of goal-directed—but uncertain—actions that frequently meet with surprises, positive as well as negative. Moreover, since a story is a rendering in language of an "adventure" that happened to some agent(s), this immediately explains why narrative exerts such a strong power on our feeling and thinking [Oatley, 1999a]. Let me now go back to the narrative worldview and try to map our new ontology of action and adventure onto its most enduring component: the *myth*.

The monomyth as archetypical storyline

Possibly the most influential general analysis of the structure of myths was made by Joseph Campbell [1949]. Campbell's thesis is that all the myths, legends and fairy tales of the different world cultures are variations on the same basic storyline, which he called the *monomyth,* and later often referred to as "the hero's journey". He summarized it as follows:

> "A hero ventures forth from the world of common day into a region of supernatural wonder: fabulous forces are there encountered and a decisive victory is won: the hero comes back from this mysterious adventure with the power to bestow boons on his fellow man." [Campbell, 1949]

The Hero

This story typically has one central protagonist, the *hero*. While the function of the hero is essentially the same in all myths, the actual properties vary. The hero can be young or old, male or female, rich and powerful or poor and destitute, human or (like in fables) animal, historically real (like Buddha or Charlemagne) or a literary creation (like Cinderella or Beowulf). That is why Campbell [1949] called his book "The Hero with a Thousand Faces". What these different incarnations of the archetypical hero have in common is that they stand out from the ordinary people: they are independent and not afraid to venture into the unknown. This natural self-assurance is due in part to certain gifts that they exhibited from an early age, such as intelligence, wisdom, strength, gentleness, courage, or beauty.

In our ontology of adventure, we may see the hero as a prototypical agent, whose abilities for autonomous action have been somewhat aggrandized in order to serve as a role model or example. The qualities that characterize the hero are the kind of qualities that support evolutionary fitness in general. The hero is merely a particularly fit exemplar of the population. That is part of what makes a myth educational: by showing how certain qualities contribute to long-term benefit, it admonishes people to promote these qualities in themselves and others.

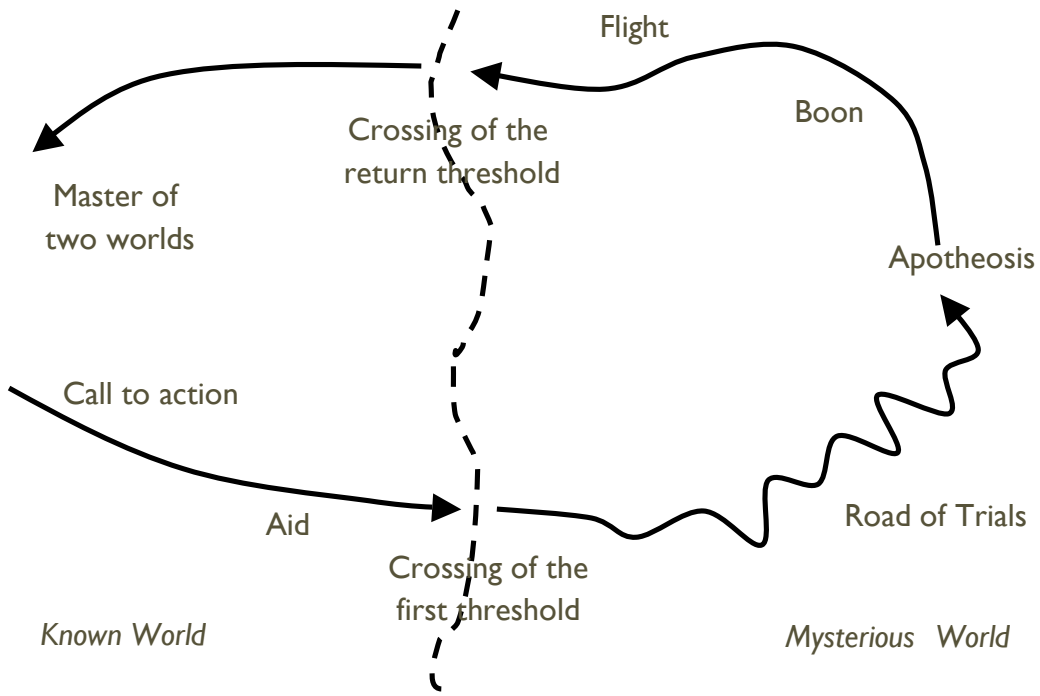

Figure 2: a simplified representation of the hero's journey according to Campbell [1949]

The hero's lack of fear for the unknown in particular is indicative of a strategy of exploration—while the ordinary people's strategy tends to be one of regulation and exploitation. By taking risks as an explorer, the hero may compensate for the more conservative, fearful strategy of the majority, and thus help the group as a whole to advance (like the ant that deviates from the path laid down by its fellows, thus possibly discovering a new food source). This is enough to make the hero into an object of admiration. Moreover, this fascination for the explorer may in part be inspired by unconscious remembrances of our past as hunter-gatherers, who indeed followed a much more explorative strategy than the ensuing farmers and industrial workers.

Stages in the Hero's Journey

Campbell [1949] identifies 17 common, archetypical stages in a typical myth. Both he and later critics note that most myths only exhibit a few of these stages. Therefore, I will not discuss all of them in detail, but focus on those that seem most universal (see Fig. 2). A typical myth will start by setting the stage with a short description of the hero's birth, upbringing, and social environment. This gives us a feeling for the "normal", i.e. known or predictable, environment.

In Campbell's terminology, the first actual stage is the "call to action": the hero receives some signal of the existence of a great danger to be tackled or an extraordinary resource to be found, i.e. a powerful challenge. As the message

typically has a mysterious origin—e.g. a dream, a manuscript found in a bottle, or an announcement made by a witch or angel—, this call can be seen as an intrusion from another, unknown realm into the everyday world. In essence, the call represents a problem to be resolved, thus defining the overall goal or quest that will direct the hero's further course of action. Perhaps after some hesitations and ruminations about whether the potential benefits outweigh the dangers (a stage called "refusal of the call"), the hero decides to follow the call and prepares for the journey into the unknown.

In this stage ("supernatural aid"), the hero typically gathers special resources that may help to cope with unfamiliar dangers. These can be material (e.g. a sword, a magic potion, or an amulet), informational (e.g. advice, a map), or social (e.g. a companion, or someone to call on in case of emergency). A classic example is the Greek myth about Theseus who receives advice together with a ball of thread from Ariadne. These resources will turn out to be critical in helping him find his way back out of the labyrinth that he is preparing to enter in order to slay the Minotaur monster that resides there.

The next stage is "the crossing of the first threshold", i.e. the actual entering into the unknown territory. Campbell emphasizes the weirdness of this transition by discussing the recurrent image of the hero being swallowed into "the belly of the whale" or other monster, thus becoming completely shut off from the normal environment. The agent is now in a different world where the rules, dangers and opportunities are not known. An example is the wonderland that Alice enters by falling into a rabbit hole or by passing through the looking glass.

While this crossing is already a severe challenge, it is merely a warming up for the next stage, "the road of trials", in which the hero has to overcome a variety of challenges that test the hero's abilities to the full. A classic example of such a series of trials are the twelve labors imposed on the Greek/Roman hero Hercules. Typical challenges involve killing a dangerous animal (often a dragon or monster), winning a combat, acquiring a hard-to-get resource (e.g. a flower, ring or sword), overcoming a physical obstacle (e.g. crossing a desert, climbing a mountain), and solving a mystery (e.g. answering a riddle, discovering a hidden treasure, or finding a way out of a labyrinth).

The series culminates in a final contest, the "apotheosis". As a reward for succeeding in this last challenge, the hero receives "the ultimate boon". This is Campbell's term for the affordance that constitutes the final goal of the hero's quest. It typically offers extraordinary powers or benefits, enabling the bearer to achieve goals or riches that otherwise would remain out of reach. Examples are the Holy Grail (whatever that may be…), the fountain of youth, the philosophers' stone, marriage to a prince or princess, a kingdom, a magic formula, or spiritual enlightenment.

The hero finally needs to bring back the boon to the ordinary world. This may involve some further complications, such as the hero preferring to stay ("refusal of the return"), having to escape from pursuers that try to recover the boon ("the magic flight"), needing a "rescue from without", or having to overcome the challenge of

integrating the extraordinary boon into ordinary life ("the crossing of the return threshold"). If everything goes well, the hero ends up as a "master of the two worlds", who feels at home both in the ordinary environment and in the mysterious realm where the boon originated, thus achieving a true "freedom to live", characterized by an absence of fear or constraint.

From this summary of the monomyth, it is clearly a depiction of the process that I have called *navigation* or *adventure*, in which an agent (the hero) follows a meandering course towards a far-away goal (the boon) that passes through an unknown or uncertain environment (the mysterious world) which throws up various, often unexpected challenges, some of which are negative (dangers), others positive (opportunities, boons). Meeting the challenge (succeeding in the quest) significantly enhances the agent's fitness, by increasing its control of external resources and/or its inner wisdom or experience. Moreover, exploration of the unknown territory results in the discovery of affordances that are now ready to be exploited (by the hero or others) thanks to the newly achieved knowledge.

From Myth to Modern Narrative

What distinguishes the heroic adventures of a mythical individual from the down-to-earth processes of regulation, exploitation and exploration that every living being has to perform is essentially *simplification*, *exaggeration* and *dramatization*. That is exactly what you would expect from a story that has been told and retold thousands of times. Both the storyteller and the listener have cognitive limitations that make that they will not be able to assimilate or remember the often-subtle details of a complex series of events involving many interacting agents. Therefore, such subtleties will disappear from the story after a few rounds of retelling, as illustrated by the experiments of Lyons and Kashima [2003]. This is likely to leave merely a straightforward plot revolving around a single protagonist. The subtle interaction between known, predictable events and unknown, mysterious influences will tend to be reduced to the simple dichotomy: ordinary world vs. magical realm.

Moreover, a good storyteller tends to aggrandize those aspects that create intense feelings in the listener. Even when the narrator does not intentionally dramatize the story, it are the most emotionally loaded episodes and story variants that are most likely to be remembered and passed on by the listeners—as confirmed by an empirical investigation of urban legends [Heath & Sternberg, 2001]. This means that, as the story evolves, both the challenges and the abilities of the agent to deal with them will tend to intensify. Thus, the beast to be confronted will not just be a wild bore with a smelly breath, but a fire-breathing dragon; the aim of the quest will not just be some precious metal, but a Holy Grail with magical powers. The hero will not just run fast, but faster than the wind; not just be strong, but strong enough to lift an ox; not just be pretty, but the most beautiful in the land.

Given this understanding of the ancient stories we find in the oral tradition of myths and fairy tales, it becomes clear how narrative has evolved into its modern forms. When stories are transmitted via writing, like in novels, there is much less need for simplification, since the paper or electronic medium takes on the role of an external memory [Clark & Chalmers, 1998; Heylighen & Vidal, 2008] that dependably registers all the details about protagonists, settings, and interactions. Moreover, with an increasingly educated, well-read and sophisticated audience, there is less need to exaggerate or to reduce subtleties to black-and-white dichotomies, and more impetus for an author to distinguish oneself and stimulate curiosity by deviating from well-known formulas.

Therefore, narrative in modern literature tends to be much more complex, involving a greater variety of agents, actions and interactions, and following an often convoluted flow of time, including flashbacks, flashforwards, and different storylines going on in parallel until they come together in the closing stages. The difference between positive (goals, affordances) and negative (anti-goals, disturbances) is less straightforward, and the actual depiction of characters and events is more realistic, in the sense of less caricatural, implausible, or simplistic. However, the basic ingredients remain the same: agents, environments and their interactions; challenges eliciting emotion and action; the tradeoffs between regulation, exploration and exploitation in deciding about and navigating along the agents' course of action; diversions producing unforeseen upsets of that course.

The complex network of interactions between these elements can be conceptualized as a *propagation of challenges*: an agent by acting on a challenge will typically change the situation so as to create a new challenge for one or more other agents. For example, consider the following simplified storyline from Hamlet: agent A in order to accede to the throne (challenge) kills his brother, the king (action). This creates a challenge for agent B, the king's son: how did his father die? Resolving that mystery produces a new challenge for B: avenging his father. But the implied course of action (killing A) now constitutes a challenge for A: how to avert the threat from B? A's likely reaction (killing or exiling B) now creates a direct challenge for A, and so on. Add to this a number of other agents (e.g. allies and rivals of A and B) affected by these actions and challenges, and acting in turn, and you have all the ingredients for a complex, dramatic plot.

Modern Myths

In spite of the greater sophistication of modern story telling, the simple and vivid structure and components of the monomyth retain a strong appeal even for contemporary audiences. Vogler [2007] wrote a frequently used handbook for novelists and screenwriters in which he uses the hero's journey as a basic scheme for developing compelling stories. For concrete examples, one can refer to the enduring popularity of 'superheroes' in movies and comic strips and of attempts to create contemporary myths, such as Tolkien's [1991] "The Lord of the Rings" trilogy, or

George Lucas's "Star Wars" series of movies. While Tolkien probably was inspired by much of the same material as his contemporary Campbell [1949], Lucas explicitly used Campbell as a source of inspiration [Vogler, 2007].

My personal preference goes to a lesser-known example, the Amber series of fantasy/science fiction novels written by Roger Zelazny [1999]. The imaginary universe created by Zelazny offers a perfect synthesis of archetypical mythical components (heroes with superhuman powers, magical realms, mythical beasts, epic battles, …) with modern realism and subtlety in the description of the characters' psychology, the complexity of their interactions, reflections and scheming, and the colorful and finely textured details of the settings. Moreover, the protagonists' ability to travel between (or is it create?) parallel universes offers a fascinating variation on the theme of crossing the threshold into a mysterious world.

But what is perhaps most remarkable is that this teeming complexity is held in check by an extremely simple, linear flow of time, centered on a single agent: the events are narrated in the first person by the main protagonist, Corwin, in the strictly chronological order as experienced by him while following an uninterrupted course of action. Even the hero's own background and character is revealed by means of such a step-by-step journey of discovery, as the novel starts with Corwin waking up in a hospital, having lost his memory, and trying to reconstruct his identity by searching for clues.

Such a first-person perspective makes it particularly easy for readers to imagine themselves perceiving the events from the hero's point of view while performing his actions. It is this internal mental simulation of the narrative's flow of action by the reader that makes a story so efficient as a vehicle to convey complex ideas and emotions [Oatley, 1999a; Heath & Heath, 2007]. Moreover, a chronological sequence of events centered on a single agent seems like the most natural format for information to easily enter episodic memory. In that sense, the hero-centered, linear structure of myths and traditional tales (whether told in the first or in the third person) may be intrinsically easier to assimilate than more complex narrative structures.

Prospect and Mystery

Landscapes of adventure

The agent's goal-directed navigation through an environment that throws up a variety of challenges may be likened to a *quest* or *search*. The notion of search has been studied extensively in the theory of problem solving [Newell & Simon, 1972]. A problem can be defined simply as a difference between the present situation (the starting point) and the desired situation (the goal, or solution of the problem) [Heylighen, 1988], but such that there is no obvious path that leads to the goal. Searching for the goal can be conceived as the heuristic exploration of a problem space, i.e. a space of possibilities or potential solutions, until an actual solution is found. A *heuristic* is a method or form of knowledge that guides the exploration

process so as to increase the probability of finding a solution, and thus reduce the amount of search needed. Heuristics do not guarantee success, however, and the result therefore remains intrinsically uncertain.

Probably the most common heuristic method is *hill climbing*. The idea is that each point in the problem space is evaluated in terms of its "goodness" or "fitness", i.e. how close it is to the ideal situation. The fitness value of a point is represented vertically, as the "elevation" of that possibility above the plane. Excellent solutions then correspond to high peaks, awful possibilities to deep valleys. This introduction of the vertical dimension to represent the fitness of a possible situation turns the problem space into a *fitness landscape* [Gavrilets, 2004]. The hill-climbing heuristic then means that the agent exploring the landscape will simply move from point to point in the direction of steepest ascent. This means that whenever the agent needs to choose between different options for the next step, it will choose the step that increases fitness most, in the hope that by continuing in this direction it will eventually reach the fitness peak, i.e. the best solution in the neighborhood. The disadvantage of the hill-climbing method is that the best local solution is in general not the best overall solution. The local hill may actually be much lower than the highest mountain. But once you are on the top of that hill all the roads by definition lead downwards, and therefore the hill-climbing method is no longer useful as a guide to indicate the highest peak.

The notions of hill-climbing and fitness landscape are defined on an abstract space of possibilities. The underlying assumption is that the agent does not know the fitness of a possibility until it has reached it. Therefore, the agent can only explore locally: it cannot plan ahead, and decide to move in a particular direction because the faraway prospect in that direction looks promising. This is a good model of totally ignorant or blind processes of exploration, such as the random variation that underlies evolution through natural selection [Campbell, 1960]. More sophisticated agents, such as animals or humans, on the other hand, can to some degree *foresee* the consequences of their actions, and thus make choices that do not immediately increase fitness because they anticipate that they will lead to greater fitness in the longer term. This implies the use of more complex and powerful heuristics than hill climbing. However, the landscape metaphor remains useful as a way to understand how the agent decides in what direction it will go. To illustrate that, we need to go back from abstract landscapes of possibilities to real landscapes with rocks and trees.

There exists an interesting scientific literature on the aesthetic qualities of landscapes [e.g. Aoki, 1999; Ruso et al., 2003]: what are the features of a landscape that make it attractive to a human observer? Some of the attraction can be explained straightforwardly on the basis of evolutionary psychology: most people like features such as lakes, animals, trees, and flowers, which indicate the presence of resources (water, food, shelter…) that enhance fitness. They similarly tend to dislike features that indicate hindrances or dangers, such as storm clouds, sharp objects, snakes, and darkness. This fits in with the postulated tendency of an agent to approach affordances

and evade disturbances. But a landscape can also exhibit more abstract features that make it attractive.

Prospect

Perhaps the most basic abstract feature characterizing attractive landscapes is *prospect* [Appleton, 1996; Hudson, 1992]. A landscape has prospect if it offers a far and wide, panoramic view. Prospect is normally high from the top of a mountain or in an open plain, and low at the bottom of a pit or in a dense, dark jungle. The more and the farther you can see, the better you can distinguish the different dangers and opportunities in your environment, and therefore the easier it becomes to plan your further course. This makes landscapes with prospect intrinsically more attractive.

In its wider sense, prospect refers to what an agent can *foresee* (prospect derives from the Latin verb *prospicere*, which means 'look forward'). Prospect in this sense is opposite to blindness, ignorance, or uncertainty—all indicating a lack of foresight. However, prospect is not the same as certainty about what will come: prospect rather indicates *potential valence*, i.e. the remote availability or presence of opportunities to be exploited or dangers to be avoided. Whether the opportunity is effectively exploited depends on the agent's course of action, and on eventual diversions interfering with that course. Note that we first introduced prospect as a binary variable that allowed us to distinguish *directions* (foreseen challenges) from *diversions* (unforeseen challenges). We are now broadening the notion of prospect to designate the extent, or sum total, of foreseen challenges. The larger the prospect, the easier it is for the agent to set out, and navigate along, a high-fitness course without risk of diversion; hence, the more the agent is in control of its near-term future. Therefore, it is clear that agents will be motivated to maximize their prospect.

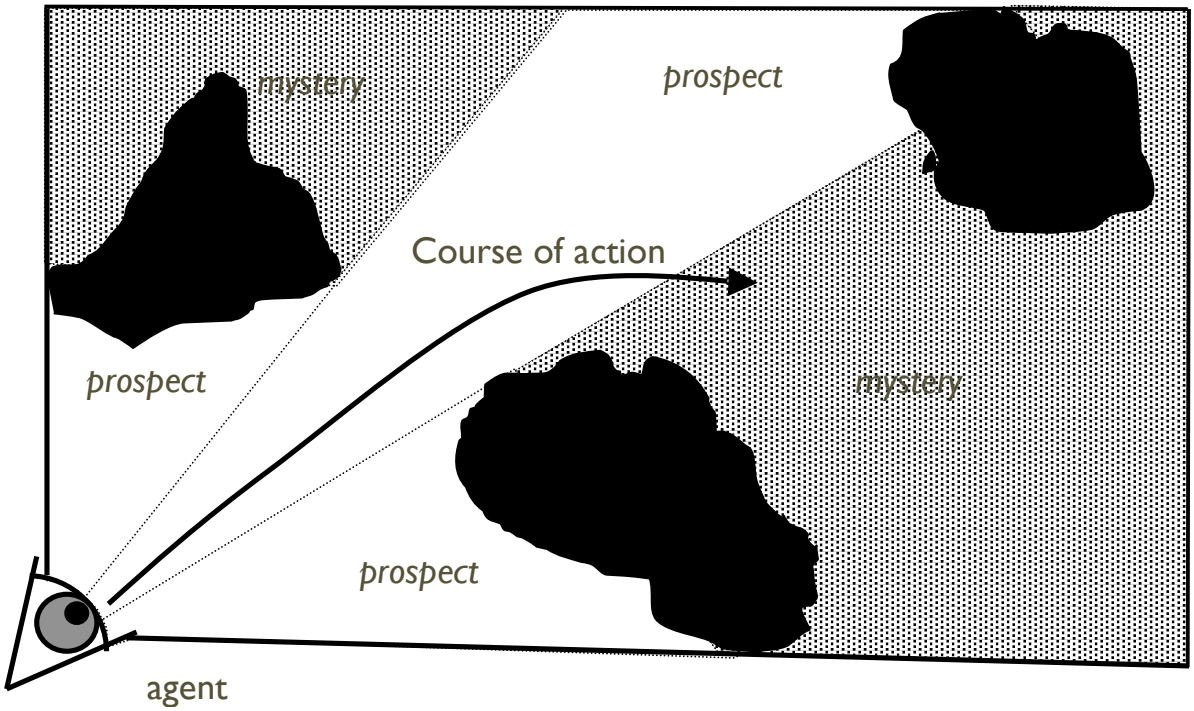

Figure 3: prospect and mystery from an agent's perspective.

White areas are regions of prospect, which the agent can perceive from its present point of view. Black shapes represent obstacles to prospect. The grey areas that are behind them relative to the agent therefore are zones of mystery, where the agent cannot foresee what it will encounter when its course of action leads it there.

Several authors [e.g. Neisser, 1976; Riegler, 2001; Hawkins & Blakeslee, 2005] have argued that prediction constitutes the essence of cognition: the function of knowledge and intelligence is to enable an agent to anticipate what it will encounter, so that it can prepare for future events by action, reflection, attention, or simply by being primed for the more likely outcomes. Obviously, the better an agent can anticipate the challenges it may encounter, the more efficient it will be in exploiting the positive ones while evading the negative ones: it is much easier to avoid a danger if you can see it coming well in time. Prospect may be defined as the *extent of this anticipation*, i.e. as the number or proportion of impending challenges that can be foreseen. As depicted in Fig. 3, prospect can be visualized as the area ahead that is perceived by the agent, either directly through its eyes (as in the case of a landscape), or more indirectly through its "mind's eye", i.e. its powers of conceptualization, inference and anticipation (as in the case of a more abstract space of possibilities).

We started from the principle that uncertainty cannot be eliminated. Therefore, *prospect is forever limited*. This is obvious in real landscapes: there are always obstacles to vision, such as hills, bushes, walls or the haze of distance. Even in a flat plain with perfect visibility you cannot see further than the horizon. Yet, with a little bit of effort obstacles can be circumvented, and sustained advance will make the

horizon recede. This brings us to a second abstract feature that makes landscapes attractive: mystery [Kaplan, 1988, 1992; Gimblett et al., 1985].

Mystery

In the aesthetics of landscape, *mystery* has been defined as "the promise of more information if one can venture deeper into the scene" [Kaplan, 1992, p. 588]. A typical example of a "mysterious" landscape is a path that bends around an obstacle so that its continuation remains invisible, or dense vegetation with a hint of a gap where one might pass through. More generally, mystery is present wherever prospect is interrupted or obscured by some kind of obstacle (see Fig. 3). However, mystery is not just the absence of prospect, but *the potential to establish an as yet non-existing prospect*. If prospect is anticipation of challenges, then mystery is a *second-order anticipation*: the prospect of prospect.

Like prospect, mystery is easily generalized from landscapes to more abstract search spaces and the courses of action that meander through them. In general, a mystery is a situation characterized by lack of knowledge, but where different clues hint at the possibility that such knowledge may be obtained given some special effort. This ties in with the Greek origin of the word, *mysterion*, which denotes a rite by which an individual is initiated into the knowledge that remains secret for the non-initiated. This word itself derives from the verb *muein*, which means "to close the eyes". Closing your eyes makes you temporarily blind (implying blockage of prospect), while maintaining the ability of opening them later (thus revealing a new prospect).

Quantitatively, we may define the magnitude or extent of a mystery as the extent of the prospect that potentially is to be revealed by resolving the mystery. While prospect invites exploitation of the prospected resources, mystery invites exploration [cf. Spielberger & Starr, 1994]. The larger the mystery, the more knowledge can potentially be gained by exploring it, and therefore the larger the potential reward in terms of increased fitness.

Mystery, in the sense of a perceived gap in one's knowledge, is a prime trigger of the emotion of *curiosity*. This emotion tends to strongly direct or drive a person's further course of action, as the subject feels an urge to "fill the gap" by seeking further information [Loewenstein, 1994; Menon & Soman, 2002; Heath & Heath, 2007]. The more an individual already knows about a situation, the stronger the urge to fill in the knowledge that still seems to be missing. Therefore, a mystery appears most attractive when it is surrounded by prospect. Why is this attraction so immediate, intense and difficult to resist? Loewenstein [1994] explains this drive by the desire for cognitive closure. But from an evolutionary perspective such cognitive drives should not be seen as primary, but as derivable from the fundamental value of fitness.

Imagine an agent in a landscape that is mostly visible, although some part of it is hidden by a rock or bush. Assuming that nothing in the prospect appears

particularly dangerous or attractive, where are the truly important disturbances (e.g. predators) or affordances (e.g. prey) most likely to be? In the hidden part! There are two arguments for this higher probability. The first—trivial or tautological—reason is that important challenges can *only* exist in the unknown part of the environment, since we started by assuming that they are not in the prospect part (if they were, *they* are likely to be the focus of attention, rather than the remaining mystery). A more constructive reason can be inferred from the nature of common challenges. As we noted earlier, affordances (such as food or gold) for which there is strong demand are likely to already have been seized by other agents. The ones most likely to remain are the ones that are difficult to find—which means that they are likely to be hidden within a "mystery zone". It is by exploring that mystery that the agent is most likely to get an edge over its competitors. Disturbances, on the other hand, have a reason to remain out of view if they are embodied as intentional agents, such as predators, enemies or criminals, with a motivation to attack the present agent.

Therefore, the priority for the agent would be to inspect the hidden section (preferably from a safe position), and thus try to fill the gap in its prospect. Ignoring that mystery may cost the agent dearly, in terms of subjecting itself to an unknown danger and/or missing out on a great opportunity. Even when in the large majority of cases the invisible spot would have nothing important to hide, the potential implications of ignoring a disturbance or affordance are too great to warrant saving a little bit of energy by not "looking around the corner". That is why, as Loewenstein [1994] observes, the feeling of curiosity elicited by a mystery tends to be intense and difficult to resist, but short-lived and with a tendency to disappoint once the missing information has come in.

Mystery is a core feature of adventure and its expression in novels, tales and others forms of narrative [Cawelti, 1976], where it functions as a powerful device to capture the attention of the audience. In film and literature, the most popular instantiation of this device can be found in the genre known as a "murder mystery". Here, the mystery in question is a crime whose perpetrator needs to be discovered on the basis of various clues [Knobloch-Westerwick & Keplinger 2006]. The narrator starts with a description of the settings, the people involved and their relationships, thus creating a detailed prospect of the environment in which the crime is going to occur. However, when then one of the protagonists gets killed, and it is not obvious how or why that happened, the remaining characters (and with them the readers) become aware of a potentially fatal gap in their knowledge that demands resolution. The rest of the story will provide a gradual filling in of that gap as new facts are revealed one by one, thus keeping the reader on alert for any potentially important clue.

A closely related genre is a thriller or suspense story. *Suspense* is a more limited form of mystery, where the outcome (e.g. an attack by the killer, or an escape from the burning building) can in general be anticipated, but where the precise timing and circumstances of that outcome remain unknown [Knobloch, 2003]. The effort demanded to get that knowledge is patience and attention to any clue, however

insignificant it may seem, in order to process it as quickly as possible in order to resolve the mystery in time for the danger to be averted. Thus, suspense is an effective method to create and sustain the focused excitement that we characterized as the fundamental "readiness for action" [Frijda et al., 1989; Frijda, 2007] that underlies the emotions necessary to live through an adventure.

Alternation between Prospect and Mystery

During a more standard adventure, prospect and mystery tend to *alternate*: the effort invested in resolving a mystery produces a new prospect; further investigation eventually runs into the limits of that knowledge (anticipation of mystery); sooner or later, the agent becomes aware of the unknown that remains hidden behind further obstacles (new mystery); elucidating that mystery engenders another prospect; and so on. This continuous alternation between the two perspectives can again be visualized as a journey meandering through a landscape.

In general, a strong excitement, feeling of freedom and sense of adventure is created by the sensation of movement along an irregular terrain, so that the vista continuously changes, and things that were hidden (mystery) come into plain view (prospect), while those that were clearly to be seen (prospect) disappear again behind the horizon (mystery). This sensation may explain the intense pleasure that people can experience while hiking through forests and hills, or driving a car or motorcycle along a scenic, winding road. This sensation is also efficiently exploited in many virtual reality computer games, where the gamer can steer a car or a running "avatar" through a 3-dimensional landscape that reveals plenty of surprises.

This joyful experience can be seen as an instance of *flow*: a feeling of total immersion into an activity that is accompanied by a sense of being in control and the vanishing of all anxiety, worry and self-consciousness [Csikszentmihalyi, 1990]. People are likely to experience flow when the following conditions are met:

- their activity has clear *goals*;
- they receive immediate *feedback* on the actions they perform.
- the degree of difficulty or *challenge* of the task remains in balance with their level of *skill*.

The first two rules express the essence of the cybernetic paradigm of regulation, while the third one implicitly adds the exploration necessary to find a new challenge when the present one has been met.

In the case of driving, elucidating the mystery of the as yet concealed landscape elements provides a challenge for further exploration. The experienced driver or hiker normally has the necessary navigating skills to meet that challenge. The new prospect that opens up behind the hill or bend in the road is the feedback signal confirming that the chosen action was indeed sufficient to meet the challenge. But his prospect immediately creates a new challenge, as further hills or twists in the road come into view, defining a new mystery that calls out for resolution…

A similar flow-producing dynamic of mysteries being resolved just in order to reveal new mysteries is efficiently exploited by writers in the mystery and suspense genres. An example is "The Da Vinci Code" [Brown, 2003], a bestselling novel that was later made into a movie. In this page-turner, the hero has to solve a series of mysteries, typically by decoding some obscure message, and then finding the place referred to in the message, only to discover another coded message hiding there. This on-going series of challenges and resolutions is made more exciting by time pressure, as the hero is being chased, both by the police for a murder that he did not commit, and by the actual murderer who is similarly searching for the solution to the mystery. The fast-paced succession of all the classic ingredients of adventure, mystery and suspense packed in a storyline that gradually elaborates plausible solutions to age-old mysteries about the Holy Grail, the Knights Templar, and the origins of Christianity may explain the extraordinary popular success of this novel.

The four dimensions of adventure

Our analysis up to now can be summarized by distinguishing four dimensions that characterize the challenges that an autonomous agent or narrative hero is likely to encounter in the course of an adventure: *positivity*, *negativity*, *prospect* and *mystery*. First, we may note that these dimensions can be grouped in opposite pairs: positive vs. negative, and prospect vs. mystery. At first sight, this reduces them to two dimensions. In reality, they are independent variables. The same challenge (e.g. encounter with a wild boar) can be both a disturbance (because a wild boar is dangerous) and an affordance (because a wild boar has tasty meat). The same landscape can offer both prospect (a panoramic view) and mystery (a view on the entrance to a cave whose content remains hidden). Still, as a simplified representation we may depict the four dimensions in a two-dimensional plane so that the "opposite" dimensions form the ends of a single axis (Fig. 4).

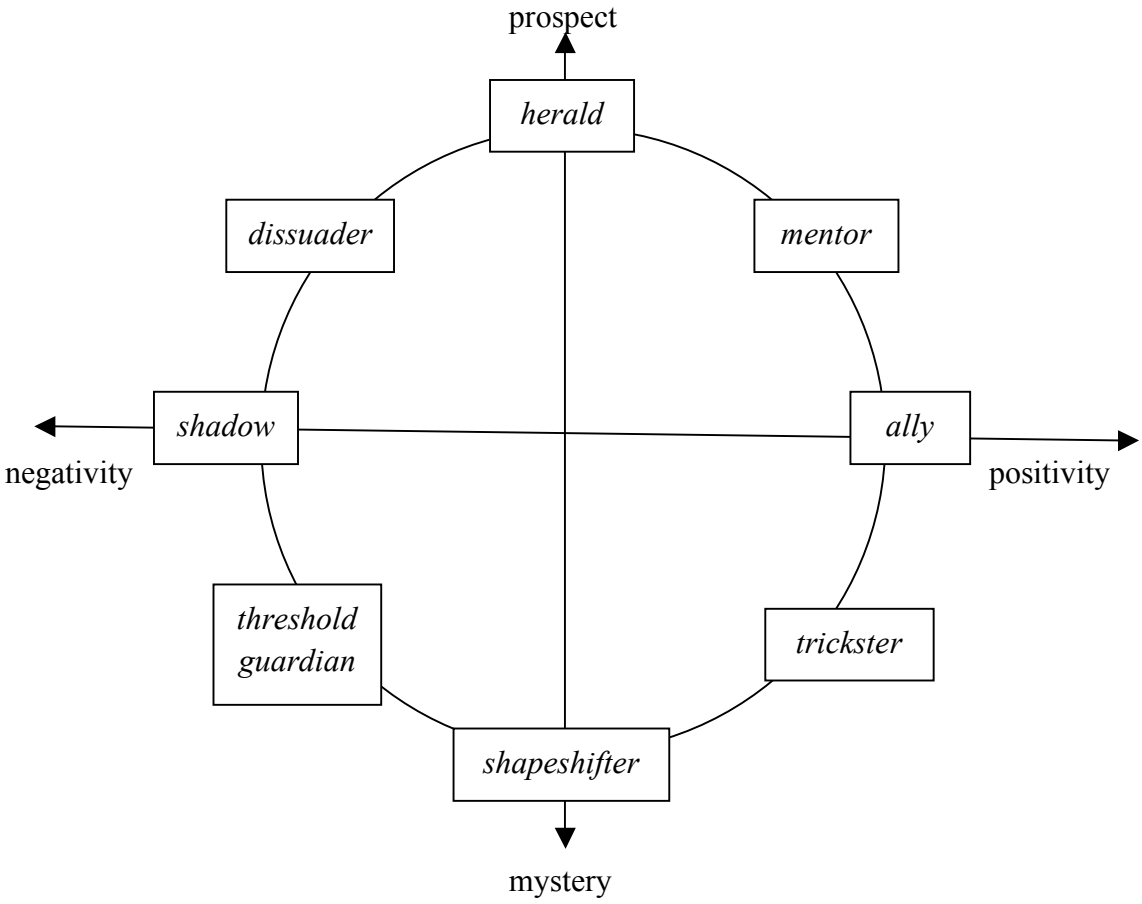

Figure 4: a two-dimensional projection of the four major dimensions of challenge (positivity, negativity, prospect and mystery) defines four quadrants, in which we can situate eight archetypical narrative functions.

These dimensions now allow us to situate or classify the challenges that make up an adventure. Vogler [2007], in his guidelines for fiction writers, proposes a simpler, more practical and more up-to-date analysis of Campbell's [1949] scheme of the hero's journey. One of his contributions is an adaptation of Jung's notion of archetype to create a list of the prototypical agents that the hero may encounter during the journey (see also [Dickey, 2006]). Note that these archetypes do not in general represent individual characters, but the functions (challenge types) that these agents perform in the adventure: the same agent may perform different functions (e.g. mentor and herald) at different stages, or the same function may be performed by different agents (e.g. the hero may have several allies or enemies). Let us survey Vogler's [2007] archetypical roles while situating them in the scheme of Fig. 4.

The "herald" is the agent that issues the call to action. It is essentially a neutral purveyor of prospect, giving the hero a glimpse of the challenges that lay in store. The "mentor" prepares the hero for the journey by giving advice on how to deal with these challenges, thus combining prospect with affordance. The "threshold guardian" tries to prevent (disturbance) the hero from entering the mysterious world, thus safeguarding its mystery. The "ally" is a friend or helper, and thus a source of positivity. The "shadow" is an enemy, rival or antagonist, who tries to thwart the hero. The "shapeshifter" is a mysterious, ambiguous character that appears in different guises, thus keeping the hero on guard, wondering who this person really is. The

"trickster", finally, plays a confusing role similar to the "shapeshifter" but more comically, making fun of the situation and of other characters, with generally positive results.

Note that after situating these seven roles in the scheme of Fig. 4, one quadrant remains empty, the one combining negativity with prospect. This suggests that we introduce an eight narrative archetype, which we might call the "dissuader". This is a common character in myths and stories whose function is to caution or scare the hero away from the enterprise (disturbance) by vividly depicting all the dangers that are in store (prospect). With all four quadrants completed, we can now note that characters in opposite quadrants also tend to perform opposite functions. For example, the dissuader (upper-left) is a conservative force, who tries to maintain the status quo, while the trickster (lower-right) likes to upset the status quo. The mentor (upper-right) facilitates the hero's entrance in the mysterious world, while the threshold guardian (lower-left) makes it more difficult.

As a reminder that this scheme is merely a two-dimensional projection of four independent dimensions, we can try to imagine what a combination of all four dimensions would look like. This would in a sense embody the "ultimate challenge", providing positive valence, negative valence, prospect, and mystery all at once. An example of such a character commonly appears in the novels and movies centered on the spy hero, James Bond, in the form of a sexy double agent. According to the intelligence Bond has gathered, she possesses crucial information (*prospect*) that may help him save the world; moreover, she seems willing to go to bed with him—a very attractive *affordance*. On the other hand, she may well have been sent to kill him—the ultimate *disturbance* to his fitness. Bond does not know whether he can trust her, but needs to find out quickly—the critical *mystery*…

Integrating Scientific and Narrative Representations

Trajectories and Observers

Starting from novel scientific concepts originating in the theories of evolution, cybernetics and complex adaptive systems, we have developed an agent-centered perspective that seems to fit in perfectly with the narrative perspective found in myths, novels and movies. However, this narrative perspective, with its emphasis on mystery, uncertainty and surprise, seems like the exact opposite of the Laplacean worldview, which is founded on complete and certain knowledge. Yet, on a deeper level these contradictory perspectives are actually surprisingly consonant. Part of the reason why the recent notion of agent was so readily accepted in science is that it is a relatively straightforward extension of the notion of dynamical system [Miller et al., 2007; Heylighen, 2009], which is itself a generalization of the way dynamics is modeled in Newtonian mechanics.

Underlying the worldview of Newton and Laplace is the notion of *trajectory*: a dynamical system follows a predictable path through its phase space or state space [Heylighen, 1988, 1990]. The basic method to determine that path is *optimization*: the trajectory is chosen in such a way that some general property of the state acquire an "optimal" value (maximal or minimal, depending on the definition of the property). This is essentially the same principle as what we have called *hill climbing*: at each point on its trajectory the system chooses as its next "destination" the point with the highest "fitness"—or whatever name is given to the property that needs to be optimized. In physics, the most common optimization criteria are potential energy, free energy, or "action"—which need to be minimized, and entropy—which needs to be maximized.

The representation in terms of potential energy is easily translated into Newton's original representation in terms of *force* (defined as the derivative of the potential energy function), which is the fundamental cause of acceleration, deceleration or change of direction. Forces play a role equivalent to *challenges*: they pull the system towards a potential energy minimum ("goal"), push it away from a potential energy maximum ("anti-goal"), or make it deviate from its straight course ("diversions"). The presence of a force means that the system has a surplus of potential energy (ability to perform work = "action readiness") that will be used to change its state of motion ("e-motion").

Like in hill climbing, the choice about what position to move to next is *local*, i.e. dependent only on the value of the optimization criterion or force in the immediate neighborhood of the present state. In that sense, mechanical systems are not subject to the complex alternation between prospect and mystery that characterizes the narrative dynamics of living agents. Mechanical systems, such as particles, cannon balls or planets, cannot anticipate and therefore cannot experience prospect or mystery. They are blind to everything except their immediate neighborhood.

However, the Newtonian worldview implicitly assumes that there is an observer who can "see" not just the neighborhood, but the whole state space and everything that is in it. This observer is typically the scientist who has accurately measured and mapped out the complete environment of the system, and used these data to build a mathematical model. Therefore, this observer can foresee the complete trajectory of the system as it will meander through this space, following the gradient that points to the successive "optimal" points. In the limit where the system encompasses the whole universe, this all-seeing observer becomes Laplace's demon. (In Newton's original, more religious interpretation, this ideal observer would have been the omniscient God). Thus, the Newtonian worldview implicitly distinguishes two agents: the system, which has zero prospect, and the observer, who has infinite prospect.

Horizons of Knowability

As we saw, twentieth century science has discovered a raft of limitation principles that all imply a restriction of prospect [Barrow, 1998; Heylighen, 1990]. Such a limit on knowledge can be interpreted as a horizon beyond which we cannot see. For example, in general relativity theory the finiteness of the speed of light entails a so-called *event horizon* surrounding a black hole. Beyond that horizon, light is "too slow" to escape from the gravitation of the black hole, and therefore from the outside it is intrinsically impossible to observe what is happening inside the horizon.

Note that the notion of horizon does not imply *absolute* unknowability. The lack of prospect is *relative* to the position from which you are looking: by moving to another place (e.g. inside the event horizon), the outlook will change, and some hidden things will become visible. But other things that were visible will at the same time disappear behind the horizon.

The same dependence on perspective underlies most limitation principles. For example, the Heisenberg uncertainty principle does not say that it is impossible to accurately measure the position or the momentum of a particle: it only states that if you accurately determine the one property, then you cannot *simultaneously* determine the other. Similarly, the theorem of Gödel does not state that the truth or falsity of certain propositions can never be established: it merely states that their truth cannot be demonstrated within a given formal system, while allowing that it may be demonstrated within an extended system—which, however, will contain other undemonstrable propositions.

This notion of *horizon of knowability* (i.e. context-dependent limitation on prospect) immediately implies the complementary notion of mystery: from a given vantage point, some things must remain hidden, i.e. mysterious, for an agent. From time to time, this mystery may intrude into the agent's course of action, producing a surprise—for example, when a ship appears on the horizon; when the agent after climbing to the top of a hill discovers a beautiful lake stretching in the distance; when a predator that was hiding in a tree suddenly jumps into plain view; or when the trajectory of a particle is deflected by one of the quantum fluctuations implied by the Heisenberg principle. Such events are what we have called "diversions". They change the prospect of challenges, and thus in general also the course along which the agent will navigate. They are in essence what makes life into an adventure.

Generalizing Scientific Models

It is this ever-changing mixture of prospect and mystery that distinguishes a real-life agent from either the prospectless dynamic system or the all-knowing Laplacean observer. Yet, at the same time, it situates the agent squarely in between these two extremes. Thus, the "life is an adventure" perspective can be seen as a straightforward generalization of the Newtonian worldview. Instead of fixing the parameter "prospect" either at zero or at infinity, it allows it to vary continuously, from zero

towards infinity (but without ever reaching the latter limit). Vice-versa, this means that the Newtonian theory can be recovered from the adventure theory as a limit case for prospect going towards infinity. This is an application of the so-called "correspondence principle", which says that the new theory (e.g. relativity theory) and the old theory (e.g. Newtonian mechanics) should produce corresponding results for the limit case (e.g. speeds much slower than light) in which the old theory has proven to be accurate.

By turning the constant "prospect" into a variable, the ontology of adventure brings the inventiveness, uncertainty and adaptivity of life, mind and society back into the scientific modeling paradigm. This newfound flexibility is part of what has made the MAS and CAS perspectives so popular in such a relatively short time: by generalizing the already successful notion of dynamic system following a (deterministic or stochastic) trajectory to the more flexible notion of agent(s) following a goal-directed course of action it has opened the way to unifying physical, biological and social sciences [Holland, 1992; Miller et al., 2007].

My contention here is that not much is needed to also include the humanities, with their focus on literature, history and religion, into that emerging unification. The agent-based approaches have as yet not explored the interactions between prospect and mystery: most agents in existing computer simulations have a fixed (and typically very limited) prospect. They can only plan one or two steps ahead. Therefore, they cannot anticipate increasing their prospect, which I defined as the experience of mystery. The only mystery exists for the observer who is running the simulation, and who is curious to see what may emerge from it. In that sense, typical agents in the CAS/MAS tradition are rather shortsighted, and would not fit into the role of a mythological hero. To recover the subtlety and complexity of human life we need a prospect that can be stretched or shrunk depending on the context, so that distant ideals can define a long-term quest, while unplanned diversions create short-term challenges.

An elegant example of such a more realistic agent-based simulation model can be found in the "virtual laboratory" designed by Gershenson [2004; Gershenson et al., 2002] to experiment with different cognitive strategies for behavior. Gershenson's agents navigate through a virtual, two-dimensional environment in search of affordances, such as food and water, while trying to avoid disturbances, such as rocks and predators. These challenges are generated by the program at random times and positions across the environment. Their appearance thus constitutes a true, unforeseeable "surprise". However, the agents have a limited prospect or field of vision (similar to the one in Fig. 3), allowing them to perceive all challenges within a certain radius and angle that are not hidden behind obstacles [Gershenson et al., 2002]. Assuming that a challenge rarely appears in their immediate vicinity, this means that they have in general time to adapt their course of action in reaction to the challenges that appear in their prospect. Thus, they can start fleeing in the opposite direction as soon as they perceive a predator ahead, or change course from a more

remote or smaller source of food to a more nearby or larger one that has just entered their field of vision.

The agent's course is visualized as a trail left behind by the agent's movements across the virtual space. This makes it possible to examine a course of action both in "narrative mode" as a real-time succession of movements, and in "scientific mode" as a fixed trajectory. The virtual laboratory synthesizes narrative and scientific perspectives in other respects too: a single "run" of the simulation can be seen as a virtual adventure, idiographically describing the things happening to a specific agent in a specific context. However, when a large number of such unique runs have been generated (differing in the values of random challenges or the initial state of the agent), it becomes possible to perform a statistical analysis of the outcomes, in order to discover possibly invariant "laws" that nomothetically apply to all "adventures". For example, such a series of experiments might find that agents who use a particular system of rules are more fit—in the sense of successfully exploiting affordances and avoiding disturbances and thus surviving—than those following different rules [Gershenson, 2004].

The formulation of such "rules of behavior" is the implicit goal of both narrative and scientific worldviews. The typical function of myths, fairy tales and fables is to teach the audience various rules of good behavior—both in the sense of moral and ethical values (e.g. help the weak, do not strive purely for material gains), and in the more pragmatic sense of problem-solving strategies (e.g. get informed well before undertaking a major enterprise, exercise in order to build physical strength). These rules are taught by illustrative stories in which the heroes who follow these rules fare well, while those who do not get in trouble. The scientific worldview eschews any notion of moral values, formulating rules or laws as "the way agents behave" rather than "the way agents *ought* to behave". But an accurate description of how things tend to behave is easily and naturally translated into a strategy for making things behave more effectively, as the endless technological and social applications of science illustrate.

Conclusion

This paper has tried to lay the foundations for a unification of the "two cultures": the scientific and narrative modes of looking at the world. At first sight, these two perspectives are completely opposed: science strives to formulate objective, timeless and context-independent laws, while narrative describes unique sequences of events happening to particular subjects in particular contexts. Moreover, science seeks rationality, clarity and predictability, while narrative delights in emotion, surprise and mystery. Yet, on a more abstract level, both aim to provide dependable knowledge, by formulating rules about how agents are supposed to behave in different circumstances. In that sense, both science and narrative function as a guiding framework that helps us to act, to decide, and to understand the complex world we live in.

My approach towards integrating these frameworks was inspired by cybernetics and by complex adaptive systems (CAS), two relatively new approaches that aim to extend scientific methods towards the more complex and dynamic phenomena that are typical of life, mind and society. Possibly the most fundamental scientific insight developed in the 20th century is the observation that there are context-dependents limits to knowledge, or what I have called "horizons of knowability". This precludes the existence of an omniscient observer like the demon of Laplace, and therefore the possibility of predicting with certainty. It entails that any realistic model of behavior will have to take into account uncertainty, mystery and surprise. Cybernetics and CAS have shown how agents can cope effectively with that uncertainty, by using regulation to control unforeseen disturbances and exploration to discover novel affordances.

I have proposed to integrate the insights from these approaches by introducing the concept of *navigation* as a combination of regulation, exploration and exploitation. Navigating means setting out and following a *course of action* while taking into account any foreseen or unforeseen challenges. Directions are the anticipated challenges, which help the agent set out its course. Diversions are the surprises that make it depart from that intended course. A course of action should therefore not be conceived as a predetermined trajectory—like the one followed by a planet around the sun—but as an *adventure*, i.e. a goal-directed activity recurrently being diverted by unpredictable and often mysterious encounters. Such challenges, whether positive, negative or neutral, are the fundamental triggers of emotions: they produce the arousal or excitement that prepares body and mind for goal-directed or corrective action.

Campbell's [1949] analysis of the "hero's journey" shows how a simplified and dramatized narration of such an adventure provides the basic storyline for all myths, legends and fairy tales: the hero (agent) in a quest (search) for a magical boon (fitness enhancing resource) explores a mysterious world (uncertain environment), having to overcome difficult trials (challenges), while sometimes receiving unexpected aid or making surprising discoveries (affordances). The same ingredients assembled in a more complex and realistic course of action and with a more subtle description of the concomitant emotions form the basis for modern forms of narrative, such as novels and movies [Vogler, 2007], or computer games [Dickey, 2006].

While navigating, agents are attracted to *prospect*, because the ability to foresee challenges helps them to set out a more effective course of action. However, at the same time they are attracted by *mystery*, which is the potential for an even better prospect. Mystery may be the most important trigger of exploratory behavior, as it invites agents to leave behind their ordinary, known environment and embark on the adventure of the unknown. Effective exploration means that mystery dissolves itself into prospect. However, the horizon of unknowability principle implies that this prospect will eventually expose new mysteries. The resulting alternation between prospect and mystery, supported by the flow experience, appears like a particularly

effective mechanism for driving the action forward—both for the agent living the adventure and for the audience empathizing with its narration.

It may even be argued that this variability of prospect is precisely what makes life most interesting, by fueling curiosity and an enduring drive for exploration. However, such a varying degree of foresight is as yet absent in scientific models of behavior. Unlike the idealized agents of Newtonian theory, real-life agents are neither blind to everything but their immediate surroundings, nor omniscient like Laplace's demon. It is as yet unclear how best to incorporate this missing dimension into scientific models, although simple computer simulations of agents navigating through a virtual environment point the way towards a first formalization and operationalization of this idea. Further research will need to address this issue in order to develop a more elaborate unification of narrative and scientific modes of representation.

What is also still lacking in the present approach is a discussion of the social interactions and relationships between agents—such as conflict, competition, alliance, friendship, and love—which form the spice of most modern narrative. Including the whole gamut of social interactions in the present—relatively simple—conceptualization of an adventure may seem like a tall order. Yet, the way to approach this problem appears straightforward. Indeed, the MAS/CAS tradition is focused especially on interactions between agents, and has produced numerous instructive models and simulations of competition, cooperation, groups, cultural diffusion, social networks etc. together with their dynamics [Miller et al., 2007]. It is actually the relative lack of analysis of individual behavior in this tradition that has prompted me to focus on the "single-hero" adventure in the present paper.

Finally, another important area for further research is the role of emotions, which I conceive as the primary mental reactions to challenges. While some of the existing theories of emotion [e.g. Frijda, 2007; Oatley, 1999b] seem quite compatible with the present perspective, it would seem worthwhile to use the present ontology of adventure as a starting point for a more detailed taxonomy of emotions, which classifies and explains feelings according to the dimensions of positivity, negativity, prospect, mystery and difficulty. This would allow a more profound analysis of which type of challenge elicits which type of feeling, and thus a better understanding of the emotional dimension that makes a good story so compelling [Heath & Heath, 2007].

References

Aerts, D., L. Apostel, Bart De Moor, Staf Hellemans, Edel Maex, Hubert Van Belle, and Jan Van der Veken. 1994. *World Views. From fragmentation to integration*. VUB Press.

Aoki, Y., 1999. Review article: trends in the study of the psychological evaluation of landscape. *Landscape research*, 24(1), 85–94.

Appleton, J., 1996. *The experience of landscape*, John Wiley & Sons Inc.

Ashby, W.R., 1964. *An introduction to cybernetics*, Methuen London.

Axelrod, R. & Cohen, M.D., 1999. Harnessing Complexity: Organizational Implications of a Scientific Frontier, Free Press.

Barrow, J.D., 1998. *Impossibility: the Science of Limits and the Limits of Science*, Oxford UP, Oxford.

Boyd, B., 2009. *On the Origin of Stories: Evolution, Cognition, and Fiction*, Belknap Press of Harvard University Press.

Brockman, J., 1995. *The third culture*, Simon & Schuster.

Brown, D., 2003. *The Da Vinci Code*, Anchor Books.

Bruner, J., 1986. *Actual minds, possible worlds*, Harvard University Press.

Campbell, D. T., 1960. Blind variation and selective retention in creative thought as in other knowledge processes. *Psychological Review*, 67(6), 380–400.

Campbell, J., 1949. *The hero with a thousand faces*, Princeton University Press.

Carver, C. S., & Scheier, M. F. (2001). *On the self-regulation of behavior*. Cambridge University Press.

Cawelti, J.G., 1976. *Adventure, mystery, and romance: Formula stories as art and popular culture*, University of Chicago Press.

Clark, A. & Chalmers, D., 1998. The extended mind. *Analysis*, 58(1), 7–19.

Cohen, J.D., McClure, S.M. & Yu, A.J., 2007. Should I stay or should I go? How the human brain manages the trade-off between exploitation and exploration. *Philosophical Transactions B*, 362(1481), 933.

Cone, J.D., 1986. Idiographic, nomothetic, and related perspectives in behavioral assessment. In R. O. Nelson & S. C. Hayes (Eds.)*: Conceptual foundations of behavioral assessment*. New York: Guilford, pp. 111–128.

Csikszentmihalyi, M., 1990. *Flow: The Psychology of Optimal Experience*, Harper & Row.

De Waele, J.P. & Harré, R., 1979. Autobiography as a psychological method. *Emerging strategies in social psychological research*, 177–224.

Dickey, M.D., 2006. Game design narrative for learning: appropriating adventure game design narrative devices and techniques for the design of interactive learning environments. *Educational Technology Research and Development*, 54(3), 245–263.

Freeth T., 2009. Decoding an Ancient Computer, *Scientific American* 301 (6), 52–59.

Frijda, N.H., 2007. *The laws of emotion*, Lawrence Erlbaum Associates.

Frijda, N.H., Kuipers, P. & Ter Schure, E., 1989. Relations among emotion, appraisal, and emotional action readiness. *Journal of Personality and Social Psychology*, 57(2), 212–228.

Gavrilets, S. 2004 Fitness Landscapes and the Origin of Species (Princeton Univ. Press.)

Gershenson, C., 2004. Cognitive paradigms: which one is the best? *Cognitive Systems Research*, 5(2), 135-156.

Gershenson, C., Gonzalez, P.P. & Negrete, J., 2002. Thinking Adaptive: Towards a Behaviours Virtual Laboratory. Arxiv preprint cs/0211028.

Gibson, J.J., 1977. The theory of affordances. In *Perceiving, acting and knowing: toward an ecological psychology*. Houghton-Mifflin, pp. 67–82.

Gigerenzer, G. & Goldstein, D.G., 1996. Reasoning the fast and frugal way: Models of bounded rationality. *Psychological review*, 103(4), 650–669.

Gimblett, H.R., Itami, R.M. & Fitzgibbon, J.E., 1985 Mystery in an information processing model of landscape preference. Landscape journal (USA), 4(2) p. 87-95

Hawkins, J., and S. Blakeslee. 2005. *On intelligence*. Owl Books.

Heath C., Bell C. & Sternberg E., 2001. Emotional Selection in Memes: The Case of Urban Legends. *Journal of Personality and Social Psychology* 81(6), 1028-1041.

Heath, C. & Heath, D., 2007. *Made to Stick: Why Some Ideas Survive and Others Die*, Random House.

Heylighen, F. & Bernheim, J., 2000. Global Progress I: empirical evidence for increasing quality of life. Journal of Happiness Studies, 13, 323-349.

Heylighen, F. & Joslyn, C., 2001. Cybernetics and Second Order Cybernetics. Encyclopedia of Physical Science & Technology, 4, 155-170.

Heylighen, F. & Vidal, C., 2008. Getting things done: the science behind stress-free productivity. *Long Range Planning*, 41(6), 585–605.

Heylighen, F. 1990: Representation and Change. A Metarepresentational Framework for the Foundations of Physical and Cognitive Science, (Communication & Cognition, Gent).

Heylighen, F. 2009: Complexity and Self-organization, in: Encyclopedia of Library and Information Sciences, eds. M. J. Bates & M. N. Maack (Taylor & Francis)

Heylighen, F., 1988. Formulating the Problem of Problem-Formulation. *Cybernetics and Systems*, 88, 949-957.

Heylighen, F., 1999. Advantages and limitations of formal expression. Foundations of Science, 4(1), 25-56.

Holland, J.H., 1992. Complex adaptive systems. Daedalus, 121(1), 17–30.

Hudson, B.J., 1992. Hunting or a sheltered life: prospects and refuges reviewed. *Landscape and Urban Planning*, 22(1), 53–57.

Kahneman, D., 2003. Maps of Bounded Rationality: Psychology for Behavioral Economics. *American Economic Review*, 93(5), 1449-1475.

Kaplan, S., 1988. Perception and landscape: conceptions and misconceptions. In (Ed. Nasar, J.) *Environmental aesthetics: Theory, research, and application*. Cambridge: Cambridge University Press, pp. 45–55.

Kaplan, S., 1992. Environmental preference in a knowledge-seeking, knowledge-using organism. *The Adapted Mind*. Ed. Jerome H. Barkow, Leda Cosmides, and John Tooby. New York: Oxford UP, 581–600.

Knobloch, S., 2003. Suspense and mystery. in: J Bryant, D Roskos-Ewoldsen, J Cantor, *Communication and emotion: Essays in honor of Dolf Zillmann*, Lawrence Erlbaum 379–396.

Knobloch-Westerwick, S. & Keplinger, C., 2006. Mystery Appeal: Effects of Uncertainty and Resolution on the Enjoyment of Mystery. *Media Psychology*, 8(3), 193.

Kramer, D.L. & Weary, D.M., 1991. Exploration versus exploitation: a field study of time allocation to environmental tracking by foraging chipmunks. *Animal Behaviour*, 41(3), 443-449.

Loewenstein, G., 1994. The psychology of curiosity: A review and reinterpretation. *Psychological Bulletin*, 116, 75–75.

Lyons A., & Kashima Y. (2003). How are stereotypes maintained through communication?: The influence of Stereotype sharedness. Journal of Personality and Social Psychology, 989-1005.

March, J.G., 1991. Exploration and exploitation in organizational learning. *Organization science*, 71–87.

McAdams, Dan (1999) `Personal Narratives and the Life Story', in L. Pervin and O. John (eds) Handbook of Personality: Theory and Research, 2nd edn, pp. 478—500. New York: Guilford

Press.

Menon, S. & Soman, D., 2002. Managing the power of curiosity for effective Web advertising strategies. *Journal of Advertising*, 31(3), 1–14.

Miller, J.H., Page, S.E. & LeBaron, B., 2007. *Complex adaptive systems: an introduction to computational models of social life*, Princeton University Press Princeton and Oxford.

Neisser, U. 1976. *Cognition and reality: Principles and implications of cognitive psychology*. Freeman San Francisco, CA.

Newell, A. & Simon, H.A., 1972. *Human problem solving*, Prentice-Hall Englewood Cliffs, NJ.

Oatley, K. 1999b. 'Emotions' in: *The MIT Encyclopedia of the Cognitive Sciences*. R. A. Wilson and F. C. Keil. Cambridge, Mass. and London,

Oatley, K., 1999a. Why fiction may be twice as true as fact: Fiction as cognitive and emotional simulation. *Review of General Psychology*, 3, 101–117.

Powers, W.T., 1973. *Behavior: The control of perception*, Aldine Chicago.

Prigogine, I. & Stengers, I., 1984. *Order out of chaos: Man's new dialogue with nature*, Bantam books.

Prigogine, I. & Stengers, I., 1997. The end of certainty: Time, chaos, and the new laws of nature, Free Press.

Riegler, A. (2001) The role of anticipation in cognition. In: Dubois, D. M. (ed) *Computing Anticipatory Systems. Proceedings of the American Institute of Physics 573*. American Institute of Physics: Melville, New York, pp. 534–541.

Rosenblueth, A., Wiener, N. & Bigelow, J., 1943. Behavior, Purpose and Teleology. Philosophy of Science, 10(1), 18-24.

Ruso, B., Renninger, L.A. & Atzwanger, K., 2003. Human Habitat Preferences: A Generative Territory for Evolutionary Aesthetics Research. In: E. Voland, K. Grammer (eds.) *Evolutionary Aesthetics* (Springer), 279–94.

Simon, H.A., 1967. Motivational and emotional controls of cognition. *Psychological review*, 74(1), 29–39.

Simon, H.A., 1982. Models of Bounded Rationality, MIT Press, Cambridge, MA.

Snow, C.P., 1961. *The two cultures and the scientific revolution: the Rede Lecture 1959*, Cambridge University Press.

Spielberger, C.D. & Starr, L.M., 1994. Curiosity and exploratory behavior. *Motivation: Theory and research*, 221–243.

Sumpter, D.J. & Beekman, M., 2003. From nonlinearity to optimality: pheromone trail foraging by ants. *Animal behaviour*, 66(2), 273–280.

Tolkien, J.R.R., 1991. The Lord of the Rings. *London: Grafton*.

Tulving E (2002). "Episodic memory: from mind to brain". Annual review of psychology 53: 1–25.

Turchin, V., 1977. The Phenomenon of Science. A Cybernetic Approach to Human Evolution. New York: Columbia University.

Veenhoven, R. 1997. Advances in Understanding Happiness. Revue Québécoise de Psychologie 182, 29-74.

Vogler, C., 2007. *The Writer's Journey: mythic structure for writers* (3rd edition), Michael Wiese Productions.

Wooldridge, M.J., 2002. *Introduction to Multiagent Systems*, Wiley. New York.

Zelazny, R., 1999. *The Great Book of Amber: The Complete Amber Chronicles, 1-10*, Eos.