Experts think together to solve hard problems
Society of Mind: Final project

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Contents

Abstract:

Most problems in the world are hard in the sense that no single person can sit down and singlehandedly solve them. Societies deal with these types of hard problems by segregating into experts that coordinate through common language and common ways to think in order to solve them. This paper discusses ways to think about experts that communicate through commonsense in order to reason efficiently about problems larger than any one person or agent could given the limited processing power of one brain or one computer as the case may be. The theory is framed by the ideas presented in The Society of Mind (SOM) and The Emotion Machine (draft) (EM)

and when possible I have attempted to apply this theory to a probabilistic model of human knowledge called LifeNet, which is in development within the Commonsense Computing group at the MIT Media Lab.

Agents in the mind are similar to people in society

> We each use terms like ``common sense'' for the things that we expect other people to know and regard as obvious. So it has different meanings for each of us.
>
> Minsky [EM 6-1]

If common sense is the collection of ways of thinking that people within a given club share, the agents within a society of mind have intricate and very personal common senses of one another because of their inherent closeness within the same mind. These agents put more emphasis on developing more specialized languages and ways to think than individual people do, but this development of specialized languages is not restricted to agents within the mind; these relationships can be thought of on human social levels by making an analogy to the development of languages and ways to think between people that live and think together for long periods of time. The people in these situations develop private shared ways to think and communicate, which are more similar to the way a society of agents within the mind might develop ways to communicate in a society of lutheran intimacy. In this essay I attempt to describe a system of communication and problem solving with a simple example using the LifeNet probabilistic model.

Language references common ways to think

Language is a means of sharing the states of our common ways of thinking. When one person gets stuck in a way of thinking while solving a problem, they can communicate the state of their way of thinking to someone who may have other ways of thinking that can help to debug the problem. Language references our common ways of thinking. These ways of thinking have the potential to create new ways of thinking so that the debugging process could involve a communication as elaborate as one agent teaching another agent a new way to think. Although, another example of language could be as simple as one agent correcting an incorrect piece of state information in another agent's similar way of thinking. The distinction between the common states of the world and the common ways to think about the states of the world becomes hard to distinguish within language because the states and the processes that generate those states often have the same reference within language. For example, there are many ways to think about the fact that there is a coffee cup on the table, so when we say ``There is a cup on the table'' we are actually referring to the common aspects of all of these ways to think; we can think in many different ways (visual, social, physical, etc.) about the cup and the language refers to some intersection of these

ways.

Different peoples' minds have similar ways to think about the cup and these are the *common senses* of the cup among these people; the differences between the individuals' ways to think about the cup are *expert senses* of the cup that are not shared between the individuals and are thus harder to communicate through shared references using language.

Using the fact that states and procedures can often be thought of as similar things, an application of this theory of expert communication through commonsense will be focused on LifeNet, which contains only statistical knowledge about the world and no procedural knowledge about how this information is derived.

Expert agents communicate using commonsense

Multiple LifeNets model social knowledge of multiple agents

LifeNet is a first person model of the knowledge state of a single agent, so we can imagine multiple LifeNets that each have a different set of expert knowledge about the world. One LifeNet could contain expert knowledge and language that medical professionals use, while another would contain expert knowledge and language that mechanical engineers use. These models of these expert individuals could each individually reason about their own domains of expertise, but when presented with a problem requiring knowledge from both domains simultaneously, each model by itself would fail to solve the problem. In order to solve complex problems involving multiple expert domains, there are two extreme types of models for problem solving that take advantage of this idea of expert commonsense:

- One large model contains all expert knowledge and performs reasoning over a sporadically connected network (containing both dense and sparse areas of the network).
- Multiple smaller expert models each contain expert knowledge restricted to one domain with all experts sparsely connected by commonsense.

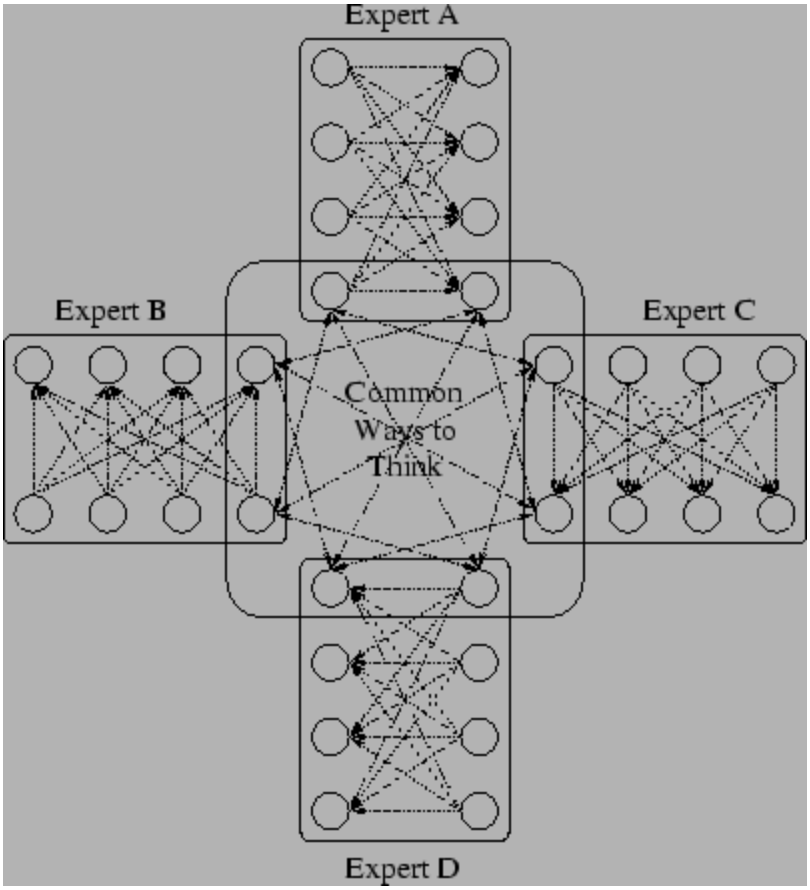

Figure: Sparsely connected dense expert models Expert models contain densely connected ways to think within themselves, but share sparsely connected common ways to think in order to reason collectively about the same problem.

There are advantages and disadvantages to each approach, but from experience slowly growing LifeNet into a larger flat knowledge base for commonsense probabilistic reasoning, we have learned that belief propagation algorithms that need to consider all states within a very large network become very slow as the number of nodes and connectivity of those nodes grows in the network. If we instead find a way to divide the reasoning network into densely connected subgraphs that can perform reasoning on independent problems in parallel, while bringing only the commonsense conclusions of these parallel reasonings to bear on the other dense subgraphs would speed up the upwards complexity of the ways to think that can be modelled.

Human societies provide an excellent example of the automatic segregation of skills that tend to disperse into the minds of people. Large societies of people are organized into problem solving teams at many levels that can take into account the different specialized abilities of those in the group in order to solve a problem efficiently that no one person could solve in the same amount of time.

When agents first meet they recognize common ways to think

When people first meet, there is a calibration period of handshaking and a general recognition of common ways to think. Both parties soon recognize similar and dissimilar ways to think that can be used for communication. When an agent first meets another agent, an *Other* model is created, which contains only the minimal set of the most common ways to think that one would assume the other person to know. As the calibration process proceeds, this *Other* model is adjusted to take into account the further similarities and differences between the ways that the *Self* model thinks and the ways that the *Other* model thinks based on inferences from the language that the other agent uses in specific contexts. [1]Once these similar and dissimilar ways to think are recognized by each of the individuals. These common ways to think can be used coordinate new ways to think by allowing the expert ways to think of each of the individuals to combine expertise.

LifeNet calibration

Recognition of shared commonsense between expert agents is an ongoing process throughout any agent relationship. This process begins by communicating a piece of knowledge and if this knowledge is unrecognized, resorting to more and more common pieces of knowledge until mutual recognition of some piece of knowledge has been made. From this shared starting set of knowledge, an island of commonsense knowledge that is specific to this relationship can be grown by incrementally sharing pieces of knowledge that are incrementally (probabilistically, procedurally, etc.) related to this initial island of knowledge. This calibration process does not only occur at the outset of a social relationship but is always taking place as the agents continue to solve problems together. [2]

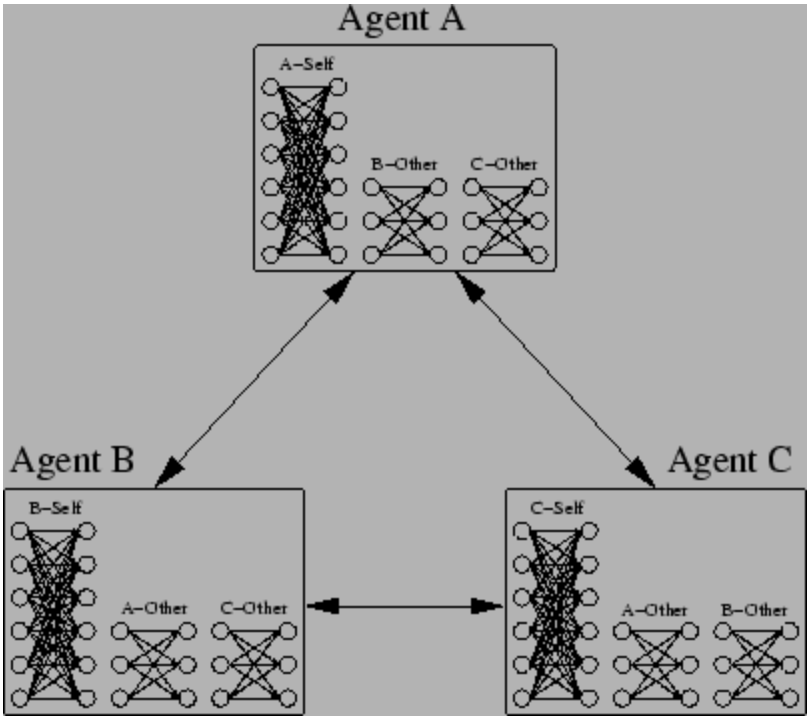

Figure: Social LifeNets with *Self* and *Other* internal models Social LifeNets communicate by reasoning over expert self knowledge and comparing these commonsense conclusions with simple internal commonsense models of other agents in the society. The *Other* models within each agent are established by a process of social calibration, which learns the similarities and differences between the ways to think in the *Self* model and the other agents in the society.

Iterative belief propagation

Social experts propagate beliefs

When communicating agents spend time together including people who spend a lot of time thinking together, what sometimes develops is the ability of the agents to work together and for each agent to solve large problems by taking advantage of the skills of the other agent. People and agents tend to specialize their skills in order to complement the skills of the society so as to raise the utility of each individual's set of skills while increasing the overall function of society. [3]The development of complementary ways to think within a society do not necessarily become more specialized, but converge on a shared set of skills, which may be used for communication and also develop a specialized set of skills that may be thought about in parallel by expert agents. For example, two agents within a society agree to work as a team to solve a given problem. First, the agents individually internalize the problem by observing the problem specifications. This could be a written document distributed to two people, or one could imagine a visual agent within the mind working with an auditory agent within the same mind working together to solve the

problem of localizing an a nearby animal. The visual agent would perceive the problem through the eyes and an auditory agent would perceive the problem through the ears in order to work together to localize an object in three dimensional space. Either way, the two agents in the society internalize a description of the problem so that each agent can then communicate their understanding of the problem space using a shared commonsense language. The visual agent might tell the auditory agent that the object is not within sight, while the auditory agent might relay to the visual agent that the object can be heard in each ear equally well, so that the communication between these agents would result in the visual agent turning the eyes to see up or down, while the auditory agent might change the shape of the ear in order to further localize the sound vertically.

Working together causes the development of new group specific ways of thinking.

As groups of agents work through problems together they begin by trying to work through the problem within their own individual set of skills and ways of thinking. If there are ways of thinking that an agent recognizes that they need but do not have, they can ask the society for an explanation of this missing way of thinking. The explanation could be as simple as communicating a bit of state information, or as complex as describing a new model for understanding the problem. Once the needed way of thinking is shared, the first agent can continue to internally solve the problem. The next time this agent comes across this same problem, it will not need to consult the group because the answer to the question has been stored within the agent. Note that the entire procedure of solving the problem is not necessarily communicated to the agent asking the question, but instead only a small approximation of the possibly very complex expert procedure needs to be communicated and remembered. The next time the group faces a similar situation, fewer questions of experts will need to be asked and more efficient processing will occur within agents in parallel because small context sensitive parts of expert procedures are transferred to other agents so that fewer questions are asked and perhaps these shared pieces of context sensitive procedures could begin to develop a referential language between agents.

Multiple expert LifeNets propagate beliefs using commonsense

The process of calibration between social expert LifeNets continues indefinitely, but this process of calibration is not the same process as the short term process of socially inferring the current state of the world. For example, the society may be able to reason about the state of the world in many different circumstances, but the skill that these agents develop by working together on these different inference problems repeatedly comes from the slow process of calibration. During the actual process of applying the calibrated models in order to solve the current transient problem, no structural calibrations are made to the expert LifeNets but only commonsense information is communicated between the social expert LifeNets.

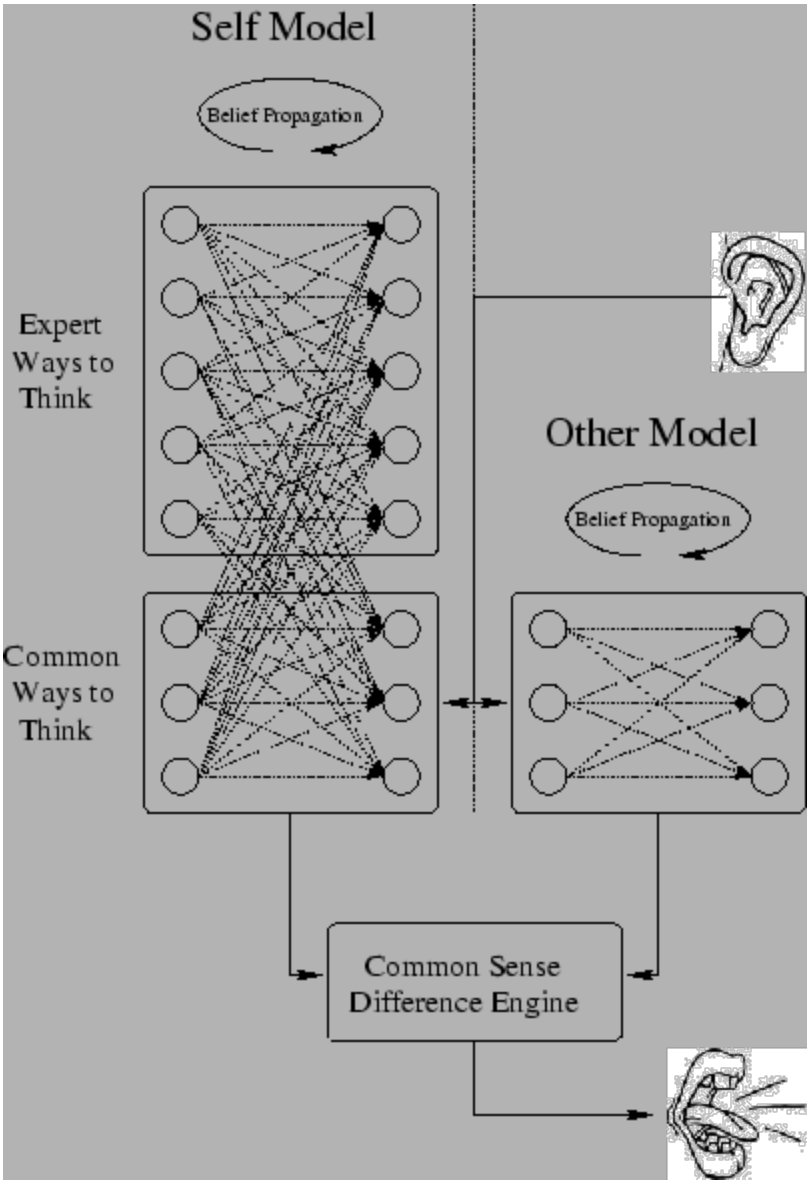

Figure: Experts communicate using common ways to think One agent uses an internal *Self* model (consisting of expert and commonsense ways to think) and a commonsense *Other* model in order to determine what another agent might not know without the expert information within this agent. A difference engine can guide a vocal dialog in order to bring the internal common sense *Other* model in agreement with the internal *Self* model's commonsense. Common ways to think can be determined by an ongoing calibration process between agents.

Internal *Self* and *Other* models

Since not all commonsense knowledge can be communicated between social experts when they are trying to solve a common problem, there must be some kind of filtering that limits the amount of information that is propagated between expert agents.

Experts can do a large amount of processing within themselves, but the commonsense connection between expert agents has been assumed to be a sparse connection with limited bandwidth.

We can imagine that each expert agent is running on a separate computer on a network with the communications between computers limited. The commonsense processing that is shared by all agents is performed in duplicate on all computers, while expert processes are computed separately on each computer and the results are shared by comparing the differences between these copies of the commonsense model that are independently computed in the context of different expert ways to think. If these commonsense models are kept synchronized with one another, the amount of information exchanged between computers is kept to a minimum while the amount of unsynchronized parallel processing is kept at a maximum.

The reason for the need for sparse connections between expert agents is expressed well in The Society of Mind :

> We usually like to think in positive terms about how various parts of systems interact. But to do that, we must first have good ideas about which aspects of a system do *not* interact-since otherwise there would be too many possibilities to consider. In other words, we have to understand *insulations* before we can comprehend interactions. To put this in a stronger form: *No complicated society would actually work if it really depended on interactions among most of its parts.*
>
> Minsky [SOM A7]

Each social agent within the society should contain and process a small commonsense model (an *Other* model) for each of the other agents within the society so that each agent can model which states of the other agents' commonsense are probably incorrect due to not having the expert information contained within the current agent's *Self* model.

So, in addition to allocating a separate LifeNet model for each person involved in the conversation, each agent must also have some sort of understanding of what the other people in the conversation know in order to only communicate pieces of information that the other individuals could not already infer themselves. We can use smaller LifeNet models for an agent's internal *Other* models, which are the commonsense models specific to each pairwise relationship between social agents in the society.

Future work

Segregating ways to think into expert domains

It would be useful for a society of experts to work together to solve large complicated problems, but how do these societies come into existence? We find ourselves surrounded by experts, but how do they become experts? Agents cannot begin as experts; many animals and arguably plants and other organisms have a lot of inborn

ways to think [4], but this does not explain how humans can learn new ways to think from their experience with the world. Societies of humans similarly do not at first keep historical records and learn to develop expert trades such as farmer and chief, but these expert domains within human societies develop after interacting with the environment and categorizing the ways to think about that environment. So, at all levels, types of expert agents become segregated within a generally useful agent in order to improve efficiency and then extra resources can be allocated to remaining problems that require new ways to think.

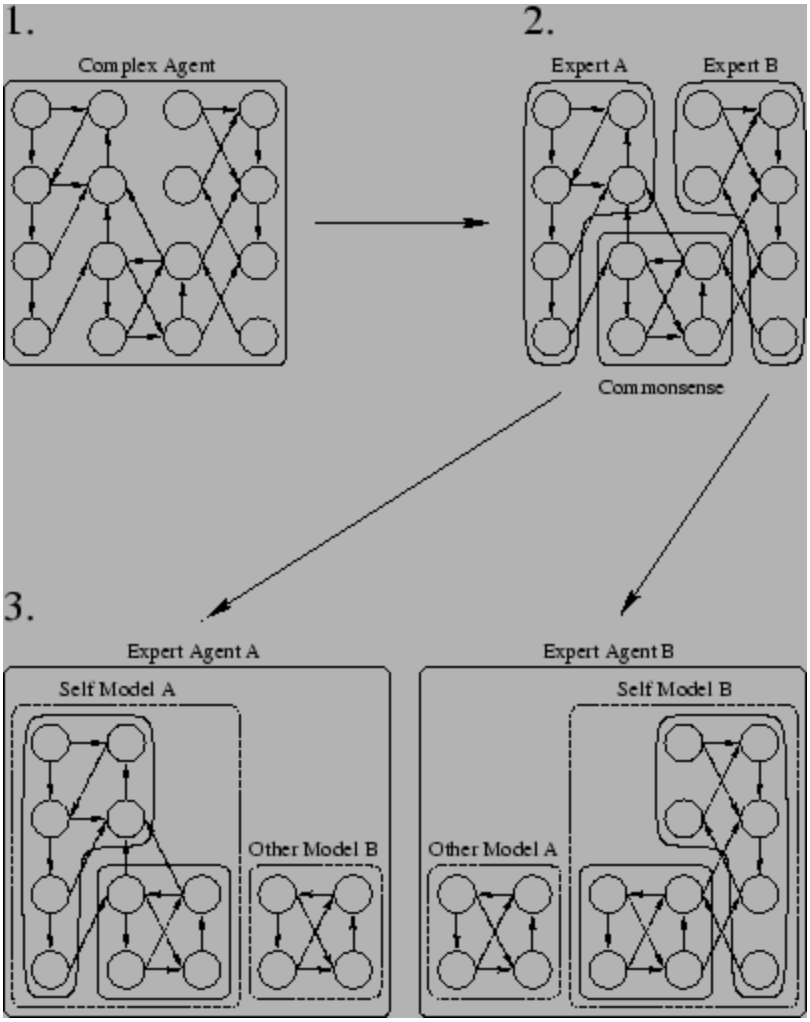

Figure: A model for how experts segregate ways to think (1) A complex agent with many interconnected ways to think can be segregated into multiple smaller agents that are experts in different domains allowing the processing to be dispersed among many experts with different ways to think and shared commonsense ways to think. (2) Partition the complex agent's ways to think into two expert domains (A and B). These expert domains will usually share a minimal set of ways to think that form a bridge between the two domains, so we call these the common ways to think, or commonsense that the two expert domains share. (3) The two expert domains and their commonsense can be used to create two new expert agents that have minimal commonsense models of each others computation that they use for communication.

Dividing large agents into multiple expert agents that communicate through commonsense within the LifeNet model is a rich domain for future research.

Disagreement and resolving conflict

What does it mean for two agents to disagree? What are possible ways for disagreement to be resolved? What are the benefits of leaving some disagreements unresolved and how do unresolved disagreements lead to trust, distrust, faith, and skepticism? Minsky provides an answer to some of these questions in The Society of Mind :

> Whenever several agents have to compete for the same resources, they are likely to get into conflicts. If those agents were left to themselves, the conflicts might persist indefinitely, and this would leave those agents paralyzed, unable to accomplish any goal.
>
> Minsky [SOM 3-2]

A disagreement can be thought of as when two agents think about a situation and come to two contradictory conclusions, which corresponds to multiple agents coming up with different goals to pursue at the moment, which would each require overlapping sets of resources. Without immediately resorting to an outside authority to resolve the conflict, a learning process can ensue if one agent recognizes a simple path through it's expert ways to think that could be taught to the other agent and then allow for an agreement. If no such simple path can be found by either of the agents, perhaps it is to the benefit of the society to trust the agent with more expert knowledge that relates to the current commonsense context. Using this sort of trust within a society allows for agents to become experts in focused domains without the need for everyone in the society to agree with the conclusions that all other agents would think about a given situation. Specific expert agents take priority in specific contexts and these priorities could be judged by other agents or are more probably understood by the expert agents themselves.

> **The Principle of Noncompromise:** The longer an internal conflict persists among an agent's subordinates, the weaker becomes that agent's status among its own competitors. If such internal problems aren't settled soon, other agents will take control and the agents formerly involved will be ``dismissed.''
>
> Minsky [SOM 3-2]

This excerpt refers to another type of disagreement that depends on higher level goals than the current commonsense context can provide. For example, if two agents are thinking toward different goals, then some disagreements need to remain unresolved in order to allow the larger goals of subsocieties to coexist within the same society; one subsociety might be working on a cure for AIDS, while another is working on a cure for world hunger, and the individuals within these two subsocieties might disagree about government spending allocations toward solving these problems, but these agents can potentially still take advantage of one anothers' expert ways to think in order to coordinate to solve common problems while disagreeing about certain ways to think. Experts will disagree, but higher order resolution strategies that decide when one agent should be trusted over another might make sense to employ in this situation - a sort of partial observer that is an expert in neither of the experts' domains but that is perhaps more of an expert in

judging the benefit of the society as a whole.

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The command line arguments were:
latex2html `-local_icons -split 0 experts_think_together.tex`

The translation was initiated by neptune on 2005-05-23

Footnotes

... contexts.[1]
This raises the question of what communication is used for. The answer to this question is as illusive as the utility of thinking itself. For the sake of the argument I will continue with the assumption that this utility exists.

... together.[2]
If a piece of information is not exactly recognized by an agent, but similarity to some internal knowledge is recognized then the states of other similar information can be communicated for verification and if this information is verified then the new piece of information can be tentatively added as being understood under the current context.

... society.[3]
This raises the question of how to measure the complementariness of skills of individuals or at a larger scope the utility of a society, but defining such a utility function is beyond the scope of this essay. I will continue under the pretense that such a function may be defined or approximated as the need to engineer a society with specified utility might arise.

... think[4]
Genetic expertise can be seen in the society of all organisms on Earth, and perhaps the same ideas of expert segregation of knowledge and ways to think could be applied to these genetic societies that accumulate segregated genetic knowledge and expertise. There is an analogous evolutionary process that occurs within a brain that learns by the directed evolution of ways to think.

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