Assignment 2: The Guessing Game

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1 Background

One of the hardest challenges in acquiring a lexicon is overcoming the inherent referential uncertainty one is faced with upon hearing a novel word. Just from perceiving an object and hearing a word that is supposedly about that object, a word learner cannot know the intended meaning of the object. This problem is commonly related to the term “referential indeterminacy”. [Quine(1960)] presented an example picturing an anthropologist studying the – unknown to him – language of a tribe. One of the natives utters the word “gavagai” after seeing a rabbit. How can, even after repeated uses of this word, the anthropologist ever come to know the meaning of “gavagai”? It could mean rabbit, an undetached rabbit part, food, running animal or even that it’s going to rain. Children are very good at dealing with this problem. From the age of around eighteen months to the age of six years, they acquire on average nine new words a day (or almost one per waking hour). They can infer usable word meanings on the basis of just a few exposures, often without explicit training or feedback – a phenomenon that is also known as fast mapping [Carey(1978), Bloom(2000)].

There exists a long history of experiments on the emergence of communication systems following the language game paradigm, both in simulated worlds and with robots interacting in real environments. Since the early nineties, the complexity of the communicative task the agents are confronted with and thus the complexity in the nature of coupling between form and meaning steadily increased. One of the first models of lexicon formation was the Naming Game [Steels(1995)], in which simulated agents have to agree on names for pre-conceptualized individual objects. Technically, they had to establish one-to-one mappings between words and (given) symbolic representations without internal structure as illustrated in figure 1a). The problem of referential uncertainty does not appear in the Naming Game – when a speaker points to an object, it is immediately clear for the hearer which individual concept to associate to a novel word. The main focus in the Naming Game was on the problem of how to reach lexical conventions and coherence in a population of interacting agents. Since each agent can invent new words for meanings, different words with the same meaning (synonyms) spread in the population, which poses the problem of reaching coherence. Agents keep different hypotheses about the meaning of a word in separate one-to-one mappings between names and individuals. Each mapping is
Figure 1: Increasing complexity in the nature of the coupling between form and meaning. Hypothetical example lexicons of one agent are shown for four different models of lexicon formation. Line widths denote different connection weights (scores). a) One-to-one mappings between names and individuals in the Naming Game. There can be competing mappings involving the same individual (synonyms). b) One-to-one mappings between words and single features in Guessing Games. Additionally to synonymy, there can be competing mappings involving the same words (homonymy). c) Many-to-one mappings between sets of features and words. In addition to synonymy and homonymy, words can be mapped to different competing sets of features that partially overlap each other.

scored and synonymy damping mechanisms, mainly based on lateral inhibition acting on these scores, were proposed to cope with the problem of incoherence.

When objects in the world are not represented as holistic symbols but instead different conceptualizations for the same object are possible, the problem of referential uncertainty appears. For example in Guessing Games such as the Talking Heads experiment [Steels and Kaplan(1999)], agents establish scored one-to-one mappings between words and perceptually grounded categories (or features, see figure 1b). Hearers need to guess which sensory quality (size, color, position, etc.) a word is about and then choose an appropriate feature for that quality. In addition to synonymy, agents can adopt mappings to different features for the same word (homonymy). The amount of referential uncertainty, as measured by the number of different hypotheses, equals the number of different features of an object representation. One proposed mechanism to overcome this uncertainty is a word learning constraint: agents choose the sensory quality that is most salient in the scene (the difference between the topic and other objects in a scene is the highest for that quality). More prominently, cross situational learning [Siskind(1996), De Beule et al.(2006)De Beule, De Vylder, and Belpaeme, Vogt and Divina(2007), Smith(2005)] has been shown to successfully solve the problem. In this approach, agents enumerate all possible meanings upon hearing a novel word and gradually refine this set by memorizing co-occurrences between forms and meanings. After many interactions, the mapping with the highest co-occurrence wins over the others and is used as the meaning of the word.
Figure 2: A toy world consisting of 10 objects (chairs) each represented by 4 features.

2 Example

Take for example the toy-world in figure 2 comprising 10 objects (chairs), each represented by 4 features. The discriminating feature-sets are depicted in figure 3.

3 Assignment: Technical Aspects

The minimal requirements for this assignment is that objects are no longer represented as (monolithic) symbols (or numbers), but are internally structured. The most straightforward way to achieve this is by representing objects as sets of features (symbols). The features themselves are now the primitives (or atoms) of meaning. If the agents would always talk about the complete objects (i.e. the complete list of features representing an object) there would be no difference to a naming game. The point is thus that agents would go beyond the use of naming-like words and could invent words for the individual categories (features). Once this is allowed the referential uncertainty (cfr. previous paragraph) comes into play because agents cannot point to individual features but only to the object as a whole. Therefore the agents need a mechanism to cope with this added uncertainty.

It is part of the assignment to come up with such a mechanism, although proposals can be found in the references. You might want to implement a discrimination component for the agents, that allows them given a context and
Figure 3: The feature sets are now as the minimally discriminating subsets that would be required to express given that the context would be the complete 10 chairs.

a topic to find a discriminating subset of the features of the topic. The speaker would then utter a sentence for this subset. As you can see the context becomes a more important aspect of the game. If all objects in the context are red it doesn’t really help to utter a word for red (if you have one).

It should by now be clear that the meaning of a word can be any subset of features of an object. So if an agent hears a novel word about an object represented by 3 features the meaning (even after pointing) can be any subset of these 3 features (except the empty one), giving rise to 7 possible interpretations. It is clear this number scales exponential, therefore it is allowed to keep the number of features per object small.

Furthermore sentences can now be comprised of multiple words. For example assume an agent has to talk about the red metal chair in figure 3 (the second from the left on the lower row). Further assume it has a word for [color-red] and one for [material-metal, has-wheels-no] (so this second word covers two features) then it would make sense to utter both of them since just saying any of these two words won’t do.

You should be able to easily play around with the following parameters:

- number of agents in the population (population-size)
- number of objects in world (size of the world)
- number of objects in context (size of the world)
- success delta (increment/decrement of scores in lexicon)
• lateral-inhibition delta (increment/decrement of scores by lateral inhibition)

You should (graphically) measure (at least) the following:

• communicative success (a running average)

• lexical coherence (you may define this yourself if you want as long as it is clear and it should be 1 when complete convention is reached).

• Amount of uncertainty. How this is implemented depends on how the agents cope with uncertainty. For example if the agents enumerate the different possibilities, the measure could simply be the average number of possibilities per word.

• average lexicon size

Technical

Your implementation should be written in Common Lisp as it is defined in the Hyperspec. Write all your code in a single file and include some code at the bottom which show how to run a series of language games.

Form

Write a small paper (max. 8 pages) in which you describe the different experiments you performed using the graphs you created. Send in your report (preferably in .pdf) together with your final code to Pieter (pieter@arti.vub.ac.be) before the deadline.

The following criteria will be used to grade your work:

• Do the agents reach communicative success? (the most minimal world would be the chairs world from section 2).

• Can the agents cope with the referential uncertainty.

• Is the code conform to a good programming style?

• Does your report conform to minimal scientific standards (e.g. are there correct citations, is it well structured, does it explain the measures, ...)

As always, you can contact me (pieter@arti.vub.ac.be) if you have any more questions, which I can believe you will have.

Deadline

Monday 07 January. (07/01/08)
References


