World Models

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Abstract

A description of how OpenCog currently implements self-awareness and world-awareness, together with a sketch of how this could be improved and expanded. The short-term goal is to create a robot (embodied chatbot) that can hear and see, and carry on conversations about perceived objects, as well as to carry out conversations about the self. These conversations can be verbal, and can also have physical-body performance components: body and face expressive movements, such as smiling or waving a hand.

Overview

The basic premise that will be elaborated here is that interacting with the world requires the creation of an internal model of the world: in systems theory, this is sometimes called "the good regulator theorem." An internal model provides the system software with a natural API, a natural representation, that various different software components can agree on, and use, and manipulate, and reason with.

AtomSpace

To acheive a unification of speech, behavior and perception, one must have a software infrastructure that allows these to be represented in a unified way: that is, the data and algorithms must reside in some unified location. From here on out, it is assumed that this unified location is the OpenCog AtomSpace. This is stated explicitly, because, in the course of discussion, various other technology platforms have been nominated. Although one could debate the merits of alternative technologies, this will not be done here.

Self Model

The self-model, and together with it, the controversial term "self-awareness", is here defined to simply be an internal model of the robot itself: both of low-level physical variables, such as motor angles, as well as higher-order concepts such as "I smiled just a few seconds ago", or "I just said this-and-such". A basic assumption taken in the following is that the engineering and design of the self-model is not any different than the engineering and design of the world-model: the data types and access methods are the same for both. Thus, ideas like "I know that my arm is raised" are represented in much the same way as "I know that there is a box in the corner of the room." Thus, in what follows, the expression "internal model" or "model" will refer to both the self-model and the world model, there being no particular difference.

State

The model is meant to implemented as "program state". In the context of OpenCog, this means that state is represented as set of Atoms in the AtomSpace: the AtomSpace is, by definition, a container designed specifically for the purpose of holding and storing Atoms. Much of this state is to be represented with the StateLink, and much of the rest with EvaluationLinks and PredicateNodes. The precise details follow what is currently the standard best-practices in OpenCog. That is, there is no particular proposal here to change how things are already handled and coded in OpenCog, although a goal here is to clarify numerous issues.

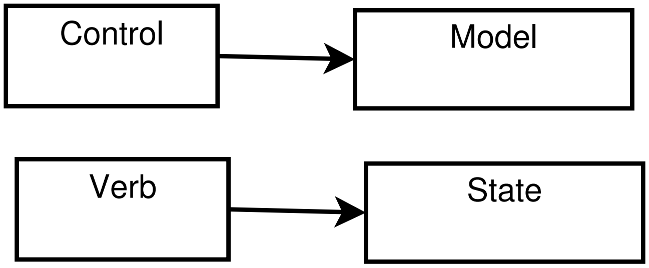
It is critically important that state be represented as Atoms, as, otherwise, there is no other practical way of providing access to that state by all of the various subsystems that need to examine and manipulate that state. This is an absolutely key insight that often seems to be lost: if the state data is placed in some C++ or Python or Scheme or Haskel class, it is essentially "invisible" to the very system that needs to work with it. This applies to any kind of state: it could be chat state (words and sentences) or visual state (pixels, 3D coordinate locations): if it is not represented as Atoms, then the myriad learning and reasoning algorithms cannot effectively act on this state. This is an absolutely key point, and is one reason why non-AtomSpace infrastructures are not being considered: they lack the representational uniformity and infrastructure needed for implementing learning and reasoning.

However, the AtomSpace does have certain peculiar performance characteristics and limitations that make it not suitable for all data: for example, one would never want to put raw video or audio into it. Yet, one does need access to such data, and so specific subsystems can be created to efficiently handle special-purpose data. A primary example of this is the SpaceTime subsystem, which represents the 3D locations of objects in an OctTree format, as well as offering a time component. Although the SpaceTime subsystem can store data in a compact internal format, it is not, however, exempt from having to work with Atoms: data must be accessible as Atoms, and suitable query API's must be provided. In this example: it is possible to query for nearby time-like events, or to answer questions about whether one object is nearer or farther, or maybe bigger or smaller, than another.

Model and Control

It is not sufficient to create an internal model of the world, and represent it as state: a control API or control language to manipulate that state must also be provided. The control is the active snippet of code that performs the actions needed to update the internal model. It can be thought of as the "control" aspect of the "model-view-controller" (MVC) paradigm from GUI programming. There are both engineering and philosophical reasons for having a control API. The engineering reasons include things like code-

Figure 1: Model and Control



The control API alters the model. It does so by applying “verbs” or “actions” to the model state.

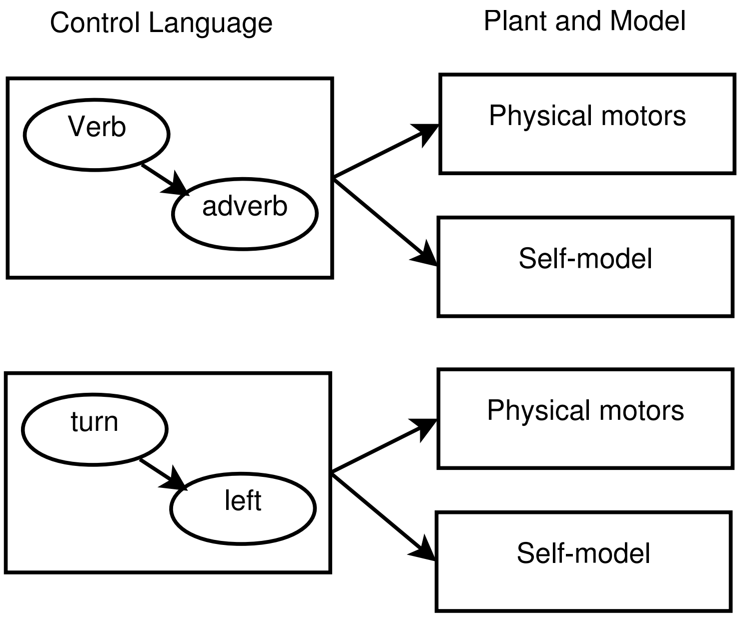
reuse, error-checking, encapsulation and ease-of-use. The philosophical reason is that a control API provides a shim between the world of static data, and the world of action and movement. That is, as events occur in time, and as the world is in flux, so must also be the internal model.

It is useful to think of the control API as a collections of “actions” or “verbs” that can be applied to “objects” (see 1). In object-oriented programming, these “actions” are usually called “methods” or “messages”. In what follows, these will often be called “verbs”, or possibly “meta-verbs” (XXX TODO: we need a good name for this). There is an important reason for this choice of terminology. First, due to the nature of how data is represented in the AtomSpace, it is the case that some given action can be applied to a large swath of the data. That is, most actions are NOT tightly coupled to the data they are manipulating, but are quite general. This means that the object-oriented paradigm does not work well with our concept of “internal model”: its not like there are many different kinds of objects, and they all need to have methods. More accurately, there are only a few kinds, and many (most?) actions are in principle (defacto?) capable of manipulating many (most?) kinds of state. The OO paradigm does not provide a good way of thinking about what goes on in the atomspace.

Another handy reason for why these “actions” can be called “verbs” is that they are really “potential actions”: nothing happens until they are performed. However, they can still be talked about, and reasoned about, and even learned: that is, the actions themselves can also be represented with Atoms, thus allowing the reasoning subsystem to make inferences such as “if I do X, then Y will happen” e.g. “if I stick out my tongue, people will laugh, or maybe they will get offended”.

In the same way that it was argued that model state must be represented in terms of OpenCog Atoms, or “atomese”, so too must be the verbs. That is, the “control API” is not some C++ code (or python or scheme or haskel...) but rather, it is also a collection of Atoms. Again, the reson for this is to allow the system to automatically generate new verbs, by means of learning, as well as to reason about the results of actions. Another key idea is that this allows actions to be combined and composed, in sequential or parallel order, with different timing. That is, the actions are primitives that can be composd into performances, that play out over time. Representing these as

Figure 2: Control Language



The control language can have a non-trivial grammar associated with it; for example, one can "turn to the left", but one cannot "turn to the eyeblink" – they eye-blink animation not being valid with the turn directive. The language can control different systems: the physical body or "plant", the internal model (or self-model, in this case), as well as models representing hypothetical future behavior, or even models that represent memories of the past. This is possible because the plant and models all use the same representation scheme, and thus, the language can act on each equally well.

atomese how such composition and performance-scripting can be acheived.

Control language

Following the idea of needing to script actions to control behaviors leads one naturally to the need for concepts such as modifiers, which come in various forms, including "adjectives" and "adverbs". So for example, if "arm" corresponds to the atomese describing a robot arm, and "raise" is an action that can be applied to "arm" (that is, the atomese for performing that action), then it is plausible to want to say "raise the left arm quickly". Here, "quickly" is the atomese needed for modulating the rate at which the motors controlling the arm are run. Likewise, "left" is the atomese specifier indicating which collection of motors are to be controlled.

Thus, the concept of a "control language" arises naturally within the system. Tghe control langauge is NOT English! Although it does have a grammar, the grammar is NOT that of English.

The need for a control language seems to be unavoidable: it is important to be able to specify motor speeds, etc. Now, if one had an object-oriented system, then one would have a "motor" object (or an "arm" object composed of "motor" objects), which had a "slot" (or "method" or "message") called "speed", and to control the arm, one would send the "fast" message to the "speed" slot (or "speed" method) on the "arm" instance. There's nothing particularly wrong with this view, except for the following points. If the OO language was C++, then the classes and methods must be known at compile time: new classes, methods and messages cannot be dynamically created, at run-time. If the OO language was Javascript, then many of these issues go away: Javascript does allow new methods to be added, at run-time, to pre-existing objects. Indeed, in many ways, OpenCog Atomese resembles JavaScript. In particular, the Javascipt members are very similiar to OpenCog Atoms, in that, at run-time, new members and methods can be added to objects. One could also say that OpenCog Atomese is a lot like JSON, in that one can specify arbitrary state structures in JSON.

There are also some important ways in which atomese differs from JavaScript or JSON: atomese allows introspection, i.e. it allows for some atoms to control and operate on other atoms, which is not possible in JSON. Atomese also provides a query language, which JSON does not provide (To understand what atomese does, one might imagine writing a SparQL or SQL wrapper to query the contents of giant blobs of JSON, or possibly dumping large blobs of JSON into Apache Solr or Lucene or Cassandra). Atomese also has other language features (it is Prolog-like, it is ML-like) that are lacking in Javascript.

Anyway, the goal here is not to debate the design of atomese, but rather to indicate that motor-control directives behave more like a language, than like an API: thus, it is more correct to think of the system as offering a "control language" rather than a "control API".

Internal model vs. physical body

The control language needs to control two distinct things: it needs to control both the internal model, and also the physical body! That is, a directive such as "raise the left arm" can be used to update the internal model, and it can also be used to control the motors on the actual physical body ("the plant", in control-theory terminology). There may also be more than one internal model: in control theory, it is not uncommon to have a "forward model", which is used to estimate what might happen if an action was performed, or an "inverse model" as an interface to the physical body. Both of these are distinct from the internal model, which models the current state, as opposed to some hypothetical future state.

Other models are possible: this includes memories of past events, where some remembered actions might be re-enacted: in this case, the remembered actions can be replayed on a remembered model, to reconstruct what happened (for example, to answer questions about those events). Another possibility is that of predicting the future, where a sequence of actions are played out on a model of the hypothetical future, to see what might happen. In such a case, there might be a model of the audience, as well as a model of the self: one is interested in predicting how the audience might react to a particular action.

Rather than inventing a new language for each of these different systems, it is convenient to be able to use the same language. The under-the-covers implementation is different: in one case, motors must be moved; in another case, the model must be updated. In either case, the verbs, nouns, adjectives and adverbs should be the same. (In control theory, this is termed the "efference copy"). This is possible as long as the differnt systems use the same underlying design scheme: as long as the underlying hypergraphs have the same structure, they can be manipulated the same way, never mond that one might represent the physical body, and another the self-model.

English language interfaces

Given the above description of the concept of "model" and "control language", one can now imagine that controlling the robot using the English language might not be too hard: just translate English to the internal control language, and one is done!

There is a prototype of this, located in github, in the nlp/chatbot-eva directory. As a prototype, it has issues: these will be discussed later. The prototype implements commands for the robot to look in different directions, and to make different facial expressions. This includes imperatives such as "look left!" and "pretend you're happy!"

Control language prototype

The control language is implemented in knowledge.scm. All of the previous discussion is made concrete in this file, and a review of this file is strongly recommended. This is where the "rubber meets the road", where things actually happen.

Lines 80 thru 120 illustrate how spatial directions are grounded in specific x,y,z coordinates. Lines 127 thru 132 associate specific English-langauge words to these directions. Lines 135-139 group the control-language direction names into a single kind (in this case, into the class "schema-direction"). This will be used later, to make sure that the "look" and "turn" verbs can only take the direction-kind, as opposed to the facial-expression-kind. This forms the foundation of a crude grammar for the control language: it will not be legal to say "turn your head to face in the happy direction".

Lines 145-149 give the two kinds to looking-turning control verbs. Lines 166-170 define the control-langauge grammar: the only valid way to move the robot head is to specify either the "turn" or the "look" verb, followed by a direction-kind. (In the current Blender animation subsystem, "turn" rotates the entire head (turning the neck) while "look" only moves the eyes.)

Lines 173-213 duplicate the earlier portion of the file, and implement the control language for the internal model (here called the "self-model", because it is modelling the robot itself).

Lines 216-306 define the control-adverbs, in one-to-one correspondance to the Blender animation names for facial expressions. There is exactly *one* control-adverb for each animation: it is not desirable to have synonyms in this layer. Line 316 defines the one and only control-verb for facial expressions: this is the "perform a facial animation" verb.

Lines 321-336 associate fifteen different English-language words with this one control-verb. This is because, in English, synonyms are common and pervasive: it is quite natural to say “Look happy!” “Act happy!” “Be happy!”, “Emote happiness!”, “Portray happiness!” and mean the same thing. Thus, all of these diferent English-language words are mapped to the same control-verb.

Lines 338-511 associate more than one hundred(!) different English-language words with the fifteen-or-so different Blender animation names. For example, “perplexity”, “puzzlement” and “confusion” are all valid synonyms for the “confused” animation.

Lines 520-531 group together the different Blender facial-exopression animations into a single animation-kind.

Lines 534-538 define the control-grammar for performing a facial animation: it must necessarily consist of the single perform-facial-animation control-verb, and one of the fifteen Blender facial-animation adverbs. No other compbination is possible: thus one cannot make the control-language statement “emote leftness”.

These control-grammar rules not only define what it is possible to do with the robot, but they also disambiguate certain English-language expressions. Very specifically, one can say, in English, “Look left!” and “Look happy!”. The English-language verb “look” is associated with both the control-language turn-verb (line 199) and also the control-language express-verb (line 335). Which of these two meanings for the English-language word “look” is intended becomes clear only after the English has been translated into conttrol-language. The control grammar allows only one, or the other meaning, depending on how it is combined with the other control-words. In particular, this means that (in this prototype), the control-words are always and necessarily unique and unambiguous in thier “meaning”. The control words provide “grounding” for meaning.

Lines 540-560 duplicate the above, but are used for controlling the self-model, instead of controlling Blender.

Lines 570-680 (end of file) repeat the previous structures, but are used to control the Blender gesture-animations (blinking, nodding, shaking, yawning). The very same concepts apply.

DRAFT VERSION 0.01

This is a draft. Everything above is in some mostly-finished state. Everything below is in outline format.

Translation prototype

The prototype includes a module that translates English language to the control language. Translation consists conceptually of two distinct aspects: mapping the syntax of the English language (grammar) to the control-language syntax (grammar), and mapping specific English-language words to control-language atoms (this second part having already been reviewed above).

The translation consists of a set of hand-crafted rules that can recognize specific kinds of English-langauge sentences, and that convert these into the internal-langauge forms.

There are several technical issues that crop up, at this point. One is that the issue: learning vs. hand-crafting, obtaining synonymous phrases, not just synonymous words.

issue: using openpsi to discover and apply rules. This is like using openpsi in general, to pick through non-verbal stimulus.

issue: fuzzy matching, partial matching

issue: picking out sentences attached to an anchor, vs other processing pipeline designs.

Question-answering

Answering questions about self and the world. Also has been prototyped. Its like the "view" part of MVC – the internal state has to be "viewed" easily, in order to be queried. Thus, there are a set of "standardized state queries", analogous to the control language. Running these queries returns yes/no answers (truth queries) or multi-valued data (e.g. look-at direction) or more complex structures (sequences of actions that had been performed in the past)

There are two translation layers that are needed here: first, to convert English to the internal query language, second, to conver the response back to English. If the response is of the right form, then SuReal can be used to perform the final conversion. Right now, the query language is not generating SuReal-compatible results.

World model

Right now, there is only a self-model. A world-model is needed, so we can talk about that. Well –there is a world model – currently, it consists of the visible faces in the environment. It needs to get bigger.

Action Orchestration

Carrying out multiple things at once; using the internal model to do this.

Memory

Multiple types of memory are needed. Most important (for demo purposes) is memory consisting of imperatives: when she is told to do this and say that, she needs to remember this, and later on, play that back as a performance.

This should be "straight-forward": one can record the control-language directives. They need to be marked up with timing information.

Implementing acting-coaching is interesting, and in particular, implementing directives such as "do that performance again, except this time, make xyz go more slowly".

A second type of memory would be remembering past states of the world.

One techical challenge is that we will need a management layer for the Postgres DB interfaces, so that memories are not lost during power-off. Those memories need to be segregated: there are somethings that need to be rememebered, others that should not be.

Free will

Free will, as defined here, is the over-riding of default behavior (as computed by psi-rules) by means of a logically, rationally reasoned course of action. For example, the default of the psi rules might be “lolly-gag about”, while a rational decision would be “go and do that important thing”. Free wil is then the act of picking between these two alternatives, of balancing them out (at a critical phase-transition point).

Items

- a person walks into room, who she recognizes. Depending on psi, she whould do non-verbal greetings (play one of 3-4 different animations (look at, chin push, nod)) and verbal greetings (“hello, what’s up, yo dawg”). split up the state and the psi rule stuff properly. See comments here: https://github.com/opencog/ros-behavior-scripting/pull/80
- extract keywords/key-topics from sentence, and remember them, then apply fuzzy matcher to see which of these come up.

Random ideas

- Why did you smile? Output: have her explain recent opensi decision-making.
- I’m so sorry about that. Output: a small cute pout (blend of frown and ???)
- Look at me. (verify look-at location or report visibility)
- What are you doing?
- (When last person leaves, she should say goodbye. If did not say goodbye, then say “hey where did everybopdy go?”)
- If no one isvisibile, and no one has been visible for many minutes, she should say “hey where did everybody go?”
- Behavior – she should not get sleepy, as long as someone is visible.
- Behavior – she should complain, if no one is visible, but there is a chat session going on.