Overview of Knowledge Representation in AI (based in part on John Bullinaria's IAI slides)

Case studies of Knowledge Representation in AI

CYC

Representations for the semantic web – from HTML to OWL

Representing human performance – CPM-GOMS
Overview of Knowledge Representation

Natural Language

Representations for search: graphs, trees, (programming constructs such as variables, lists, vectors, arrays,) (and many more AI representations from the lists below)

Logic: Propositional Logic, First Order Predicate Logic, Higher Order Predicate Logic, Modal Logic, Temporal Logic, Fuzzy Logic (and many more)

Planning: Situation Calculus, STRIPS (in many variations (ie GRAPHPLAN with STRIPS), and other representations)

Alternatives to full logics: semantic networks, frames, scripts, object oriented programming, production rules, databases, agents with no central representation

Representations for dealing with learning and uncertainty: Neural Networks, Decision Trees, Support Vector Machines, Inductive Logic Programming, Genetic Algorithms, Genetic Programming, Bayesian Networks (and many more)
Why do we need alternatives to logic?

In last lecture we talked about Frame Problem, and how it may apply to all declarative forms of representation.

There are a number of other reasons why alternative representations have been suggested.

Logical equivalences sometimes don't match our intuitive understanding.

For example, Luger (page 199) notes that the sentence:

\[ \forall X \ (\text{cardinal}(X) \rightarrow \text{red}(X)) \]

logically equivalent to:

\[ \forall X \ (\neg \text{red}(X) \rightarrow \neg \text{cardinal}(X)) \]

But this equivalence doesn't match the implications humans would derive from these sentences, for example does the whiteness of a sheet of paper provide evidence that cardinals are red?
More on alternatives to logic

Semantic networks, - hierarchy of ISA links

Frames – slots and inheritance

Scripts, - captures expectations in routine experiences, eg restaurant script

Semantic Networks were in 19 by Peirce but became popularised after Quillian found psychological evidence that human knowledge is stored similarly to the hierarchical taxonomies formed by semantic networks

For example, it takes humans longer to answer the question 'can a canary breathe?', less time to answer the question 'can a canary fly?' and less time again to answer the question 'can a canary sing?'

Why might this be? Think about how the data used to answer these questions might be represented

None of these really radical alternatives to logic, but cut-down versions of logic that we might call 'logic-like representations'
More on 'logic-like' alternatives to logic

There is a trade-off between expressiveness and ease of efficiency of manipulation

Semantic networks and Frames have difficulty in expressing certain kinds of knowledge. For example, it is difficult, but not impossible to express disjunctions (and thus implications), negations, and general non-taxonomic knowledge (Nilsson page 512)

Legacy of Frames and Semantic Networks: idea of hierarchies of inheritance led in part to the development of Object oriented programming, one of many examples of developments in AI feeding into regular computer science and software engineering

still used in expert systems

trade-off of general purpose versus specialist knowledge
Even more on alternatives to logic

Databases,

Not much variety in how can reason about items – just look-up.
Can represent entities and relationships between entities, but not much more.

Production rules,

If Production rules match items in a database, what form are these items in? Are Production rules a radical alternative from logic?

Agents with no central representation

Neural networks and behaviour based robotics are two examples of AI techniques that are radically different from
Agents with no central representation

Rodney Brooks (1991) criticised the AI and cognitive science of the day because much work treated behaviour at a very abstract level and assumed that intelligence came from central, abstract, logic-like, representations that could be studied top-down:

“Human level intelligence has provided us with an existence proof, but we must be careful about what lessons are to be gained from it.

A story: Suppose it is the 1890's. Artificial flight is the glamor subject in science, engineering, and venture capital circles. A bunch of AF researchers are miraculously transported by a time machine to the 1990's for a few hours. They spend the whole time in the passenger cabin of a commercial passenger Boeing 747 on a medium duration flight.

Returned to the 1890's they feel invigorated, knowing that AF is possible on a grand scale. They immediately set to work duplicating what they have seen. They make great progress in designing pitched seats, double pane windows, and know that if only they can figure out those weird 'plastics' they will have the grail within their grasp.”

Brooks's criticism is a call to bottom-up research where whole embodied agents are formed to manipulate objects and navigate un-aided in their environments without high-level planners.
What do knowledge representations have in common?

The units or atoms of the representation (for some representations this would be called the lexical part). Examples: logical terms and logical connectives, neurons in a ANN, nodes in a Bayesian Network, nodes and ISA links in a Semantic Network

The structural or syntactic part, - that describes the constraints on how the components can be organised i.e. a grammar.

The semantic part – that establishes way of associating real world meanings with the representations

The procedural part – that specifies the access procedures that enables ways of creating and modifying representations and answering questions using them, ie how we generate and compute things with the representations
Requirements of a Knowledge Representation

A good knowledge representation system for any particular domain should possess the following properties:

**Representational adequacy** – the ability to represent all the different kinds of knowledge that might be needed in that domain

**Inferential adequacy** – the ability to manipulate the representational structures to derive new structures (corresponding to new knowledge) from existing structures.

**Inferential efficiency** – the ability to incorporate additional information into the knowledge structure which can be used to focus the attention of the inference mechanisms in the most promising directions.

**Acquisitional efficiency** – that specifies the access procedures that enables ways of creating and modifying representations and answering questions using them, ie how we generate and compute things with the representations.

Finding a system that optimises these for all possible domains is not going to be tractable. The basic trade-off is between expressiveness and ease and efficiency of use.
Practical aspects of good representations

In practice, the theoretical requirements for good representations can usually be achieved by dealing appropriately with a number of practical requirements.

1. The representations need to be complete – so that everything that could possibly need to be represented, can easily be represented

2. They must be computable – implementable with standard computing procedures

3. They should make the important objects and relations explicit and accessible – so that it is easy to see what is going on, and how the various components interact

4. They should suppress irrelevant detail – so that rarely used details don't introduce unnecessary complications, but are still available when needed

5. They should expose any natural contraints – so that it is easy to express how one object or relation influences another

6. They should be transparent – so you can easily understand what is being said

7. The implementation needs to be concise and fast – so that information can be stored, retrieved and manipulated rapidly
CYC

CYC is aimed to reproduce human competence in common-sense reasoning. It can be viewed as an expert system that spans all everyday objects and actions

For example CYC knows that:

You have to be awake to eat

You cannot remember events that have not happened yet

If you cut a lump of peanut butter in half then each half is also a lump of peanut butter; but if you cut a table in half, neither half is a table
Some examples of the kind of knowledge in CYC (from wikipedia)

(#$isa #$BillClinton #$UnitedStatesPresident)

"Bill Clinton belongs to the collection of U.S. presidents"

(#$genls #$Tree-ThePlant #$Plant)

"All trees are plants".

(#$capitalCity #$France #$Paris)

"Paris is the capital of France."
Sentences can also contain variables, strings starting with "?". These sentences are called "rules". One important rule asserted about the #$isa predicate reads:

(#$implies
   (#$and
      (#$isa ?OBJ ?SUBSET)
      (#$genls ?SUBSET ?SUPERSET))
   (#$isa ?OBJ ?SUPERSET))

with the interpretation "if OBJ is an instance of the collection SUBSET and SUBSET is a subcollection of SUPERSET, then OBJ is an instance of the collection SUPERSET".
Another typical example is:

\( (\text{relationAllExists} \#\text{biologicalMother} \#\text{ChordataPhylum} \#\text{FemaleAnimal}) \)

which means that for every instance of the collection \#\text{ChordataPhylum} (i.e. for every chordate), there exists a female animal (instance of \#\text{FemaleAnimal}) which is its mother (described by the predicate \#\text{biologicalMother}).
The knowledge base is divided into *microtheories* (Mt), collections of concepts and facts typically pertaining to one particular realm of knowledge. Unlike the knowledge base as a whole, each microtheory is required to be free from contradictions. Each microtheory has a name which is a regular constant; microtheory constants contain the string "Mt" by convention.

An example is #$MathMt$, the microtheory containing mathematical knowledge. The microtheories can inherit from each other and are organized in a hierarchy: one specialization of #$MathMt$ is #$GeometryGMt$, the microtheory about geometry.
The Semantic Web

**OWL** (web ontology language – three different versions all based upon subsets of predicate logic)

**RDFS** (resource description framework schema – stronger semantics but full expressive power of predicate logic)

**RDF** (resource description framework - easily machine readable in standardised form to aid communication across web – but weak semantics)

**XML** (tags are easily machine readable – but not in standardised form to aid communication across web)

**HTML and natural language** — not easily machine readable
Comparing CYC and the Semantic Web

A key difference is that CYC is attempting to more closely capture a human level of commonsense knowledge.

The semantic web is more directed to supporting computer to computer communication – the automation of specific activities that would have previously required human intervention

Put another way, CYC is a theorem prover, whereas the semantic web is a theorem validator (the should-I-trust-you-button)

A key similarity is that they have both naturally moved to incorporate more strongly logical representations because of the expressivity that these representations provide, and despite the problems in efficient reasoning that these more expressive representations bring with them. OpenCYC, and open source version of CYC has been rewritten in OWL for use on the semantic web.
Project Ernestine and CPM-GOMS

AND NOW FOR SOMETHING COMPLETELY DIFFERENT!

(which links nicely with our next three lectures)

What are the really radical alternative to logic?

We have already seen ANN's and behaviour based robotics.

There are many others.

One high level way of representing human performance is CPM-GOMS

Other similar cognitive-orientated representations such as ACT-R will be discussed in the next two lectures
Project Ernestine and CPM-GOMS

GOMS = goals, operators, methods, selection rules (used in HCI/usability)

CPM = cognitive perceptual motor OR critical path method

CPM-GOMS is different to other flavours of GOMS because it allows modelling of human performance on tasks that involve parallel processing

Used to model TAO workstations (toll-and-operator, in UK when you call 150)

Each worker has hundreds of calls per day, so decreasing the time for an average call might save millions of dollars.

NYNEX workstations were old, and a new workstation was offered by another company.

HOW TO EVALUATE THE NEW WORKSTATION?
A cognitive prediction of performance was compared with a non-cognitive prediction.

New workstation was evaluated in three ways:

A non-cognitive prediction that measured number of key presses and distance fingers needed to travel to fulfil tasks.

A cognitive prediction that was provided by CPM-GOMS and considered how actions could be taken in parallel using the critical path method.

An empirical pilot study of tao operators using the new workstation.

The non-cognitive prediction suggested the workstation would save millions of dollars.

The cognitive prediction and empirical pilot study showed the reverse!
Overview of Knowledge Representation

The key kind of representation in AI are logical representations.

Many alternatives to logical representations are still 'logic-like'.

There are also more radical alternatives that include representations used by cognitive science to explain biological intelligence.

Biological intelligence is the subject of the next two lectures.