Knowledge Representation

and

Reasoning

Introduction

Deepak Khemani

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Text books and references

Text Books

1. Ronald J. Brachman, Hector J. Levesque: Knowledge Representation and Reasoning, Morgan Kaufmann, 2004.
2. Deepak Khemani. A First Course in Artificial Intelligence, McGraw Hill Education (India), 2013.

Reference Books

1. Schank, Roger C., Robert P. Abelson: Scripts, Plans, Goals, and Understanding: An Inquiry into Human Knowledge Structures. Hillsdale, NJ: Lawrence Erlbaum, 1977.
2. R. C. Schank and C. K. Riesbeck: Inside Computer Understanding: Five Programs Plus Miniatures, Lawrence Erlbaum, 1981.
3. Murray Shanahan: A Circumscriptive Calculus of Events. Artif. Intell. 77(2), pp. 249-284, 1995.
4. Grigoris Antoniou and Frank van Harmelen, A Semantic Web Primer, 2nd Ed, MIT Press, 2008.
5. John F. Sowa: Conceptual Structures: Information Processing in Mind and Machine, Addison–Wesley Publishing Company, Reading Massachusetts, 1984.
6. John F. Sowa: Knowledge Representation: Logical, Philosophical, and Computational Foundations, Brooks/Cole, Thomson Learning, 2000.

We know….

"*You will not apply my precept," he said, shaking his head. "How often have I said to you that when you have eliminated the impossible, whatever remains, however improbable, must be the truth?*

We know that he did not come through the door, the window, or the chimney. We also know that he could not have been concealed in the room, as there is no concealment possible. When, then, did he come?"

- Sherlock Holmes in *The Sign of the Four*
(by, Arthur Conan Doyle, ch. 6, (1890)

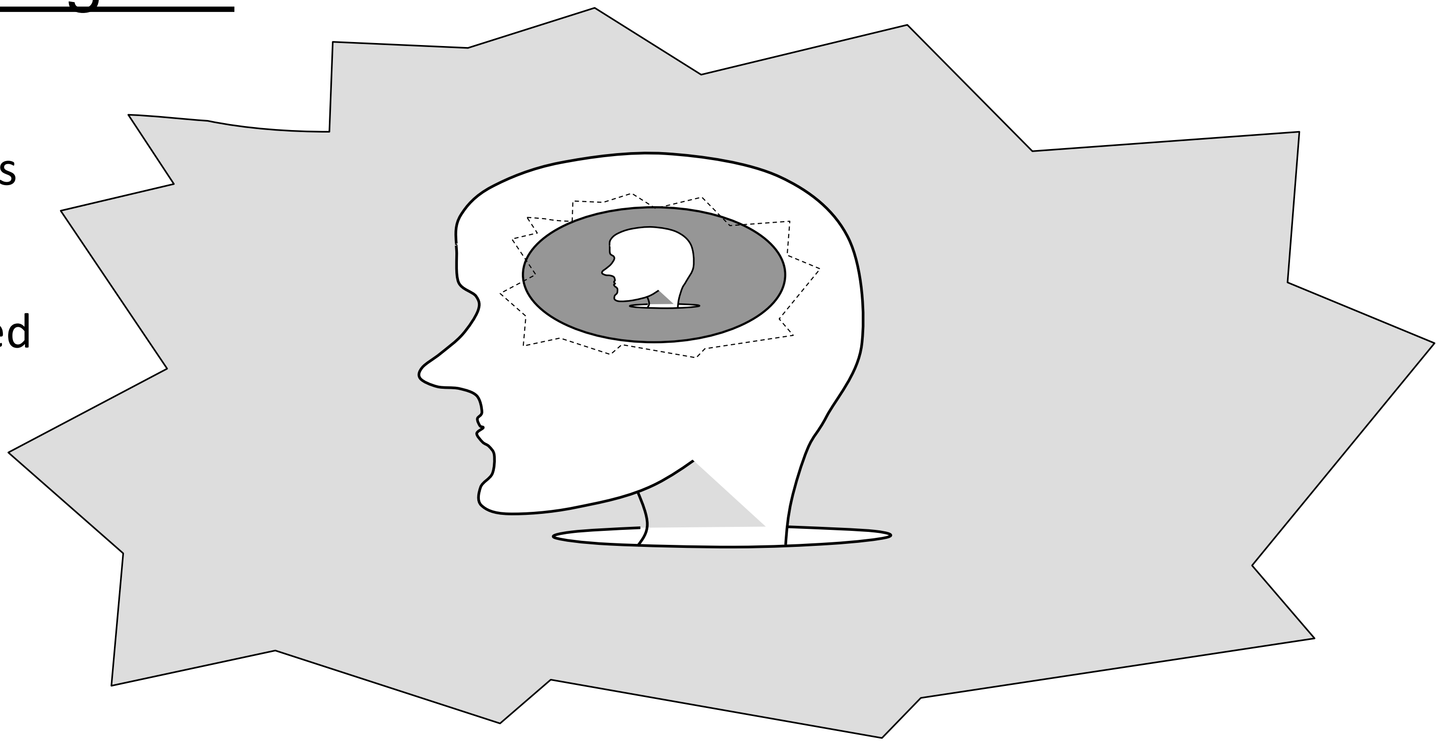
Intelligent Agents

Persistent

Autonomous

Proactive

Goal Directed



An intelligent agent in a world carries a model of the world in its “head”. The model is an abstraction, like all models. A self aware agent would model itself in the world model.

(From A First Course in AI – Deepak Khemani)

On Knowing

There are several ways one can *know* something

- Empiricism: involves acquiring knowledge through observation and experience.
  - Seeing is believing? Mind the deep fake videos
- The scientific method: is a process of systematically collecting and evaluating evidence to test ideas and answer questions.
- Intuition: Rather than examining facts or using rational thought, intuition involves believing what feels true.
- Authority: Accepting ideas because some authority figure says that they are true.
  - "*My teacher / mother said so*"!
- Rationalism: involves using logic and reasoning to acquire new knowledge.

https://opentext.wsu.edu/carriecuttler/chapter/methods-of-knowing/

Reasoning = Making Inferences

If an agent knows something
what *else* can the agent know?

Three Types of Inference

- Deduction: From a given set of facts infer another fact that is *necessarily* true
  - From Cause to Effect
- Abduction: From a given set of facts infer another fact that is *possibly* true
  - From Effect to Cause
- Induction: From a given *sets of facts* infer a new fact.
  - Also known as generalization. Recognizing that a number of entities in the domain share some common property, and assert that as a general statement
  - The peepul leaf is green
  - The tamarind leaf is green
  - The neem leaf is green
  - The mango leaf is green
  - .
  - .
  - All leaves are green.

Deduction

"*Beyond the obvious facts that he has at some time done manual labour, that he takes snuff, that he is a Freemason, that he has been in China, and that he has done a considerable amount of writing lately, I can deduce* nothing else*."

— Arthur Conan Doyle,
[The Red-Headed League - a Sherlock Holmes Short Story]

"*Crime is common. Logic is rare. Therefore it is upon the logic rather than upon the crime that you should dwell*."

— Arthur Conan Doyle, *The Adventure of the Copper Beeches*

* In fact some of these inferences are *abduction*

Abduction needs to be consistent

“*The man might have died in a fit; but then the jewels are missing*," mused the Inspector, "*Ha! I have a theory. These flashes come upon me at times... What do you think of this, Holmes? Sholto was, on his own confession, with his brother last night. The brother died in a fit, on which Sholto walked off the treasure! How's that*?”

"*On which the dead man very considerately got up and locked the door on the inside*," said Holmes.”

— Arthur Conan Doyle, The Sign of Four

Epistemic Logic

Epistemic logics deal with multiagent systems. It allows us to represent statements about what an agent knows about what other agents know.

Doxastic logics talk about belief instead to knowledge.

Knowledge is about facts. Beliefs may be false.

- "*My name is Sherlock Holmes. It is my business to know what other people do not know*."
  — Arthur Conan Doyle, *The Adventure of the Blue Carbuncle*

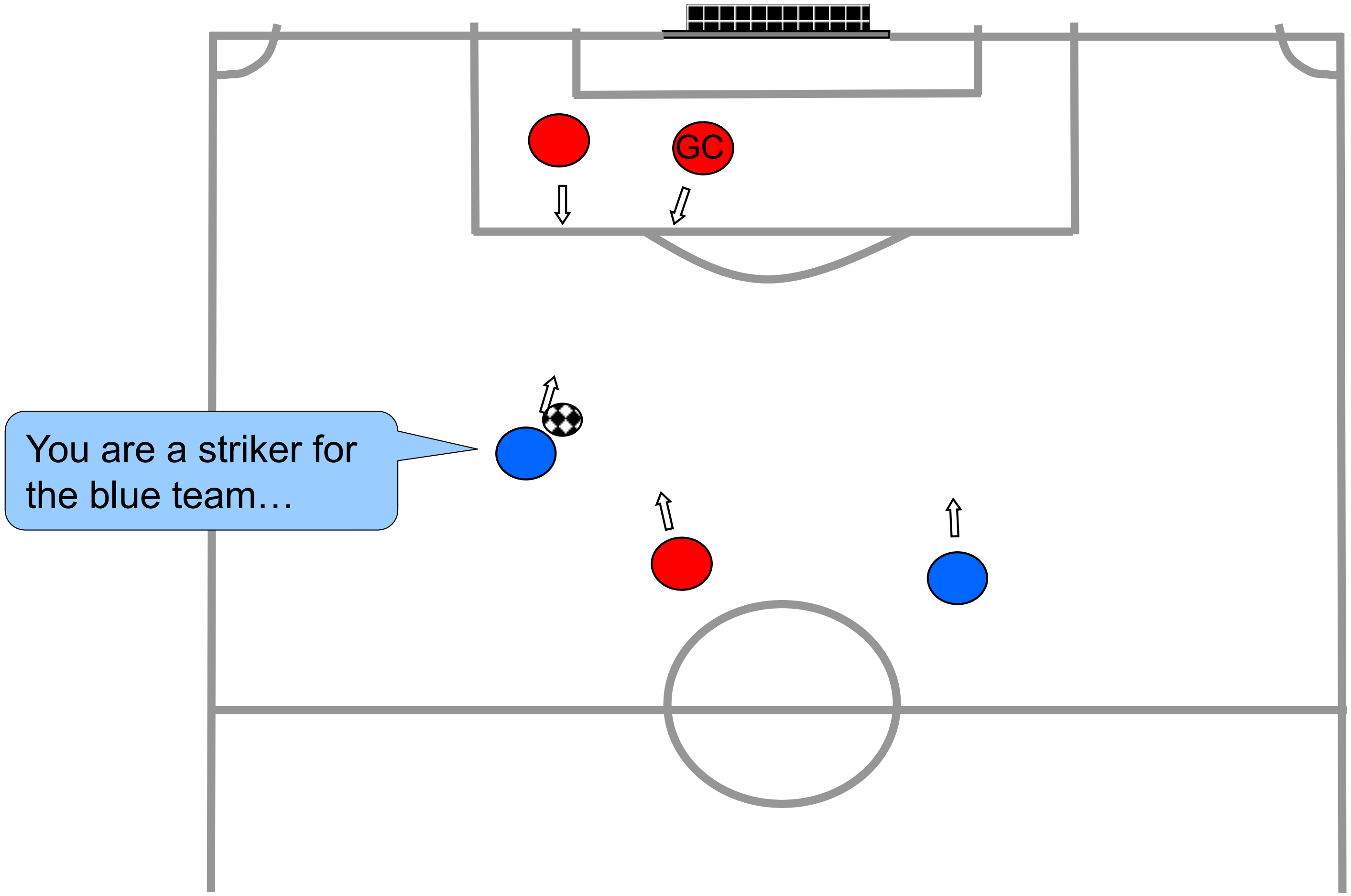
- "*What you do in this world is a matter of no consequence. The question is what can you make people believe you have done*."
  — Arthur Conan Doyle, A Study in Scarlet

Induction: What is the next number in the series?

- 1, 2, 3, 4, ….. 5?
- 2, 4, 6, 8, … 10?
- 1, 1, 2, 3, 5, … 8?
- 1, 4, 9, 16, … 25?
- 0, 3, 8, 15, … 24?
- 0, 0, 0, 0, … 0?

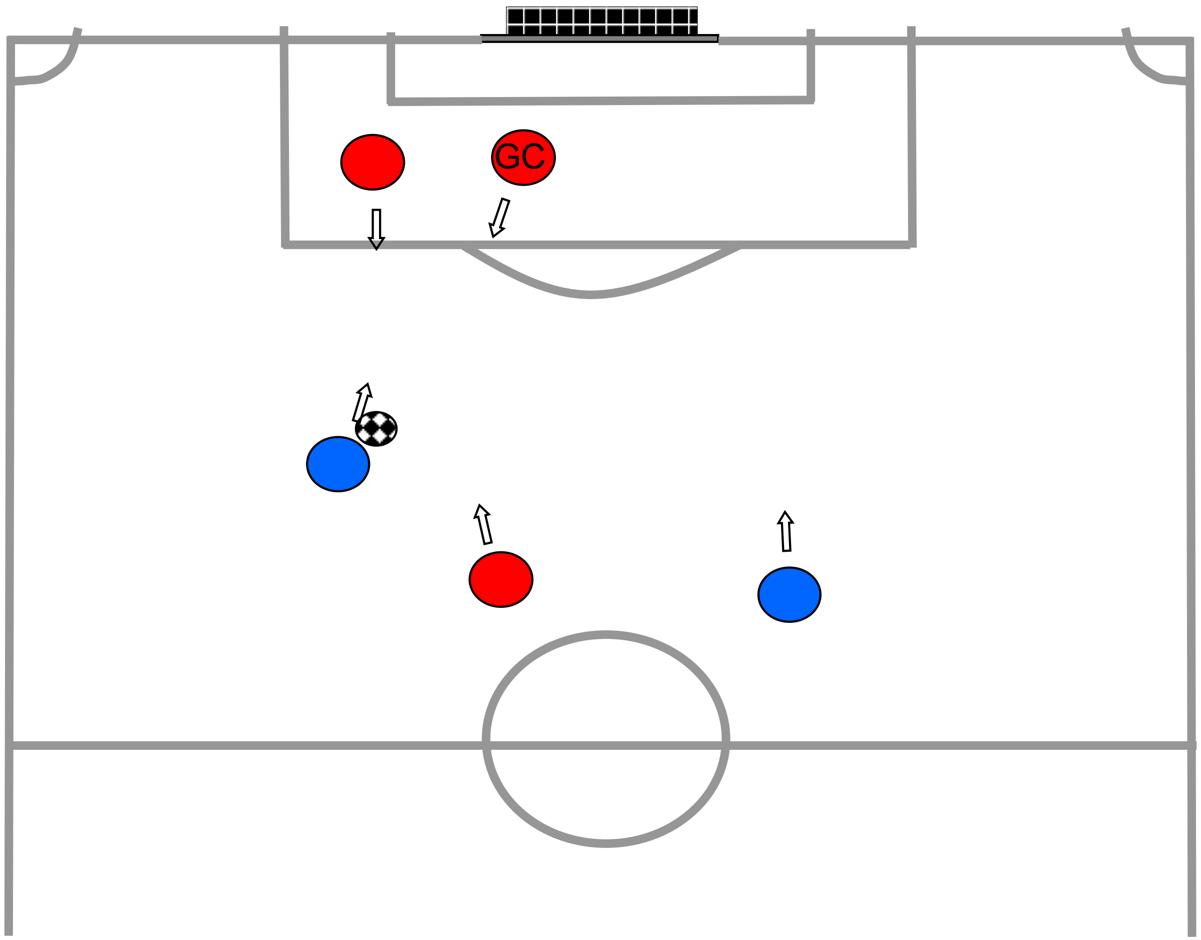
  But what if we are generating
  the values from (N-1)(N-2)(N-3)(N-4)?

On a football field…



Recap from SMAI

.. moving forward with the ball…



Recap from SMAI

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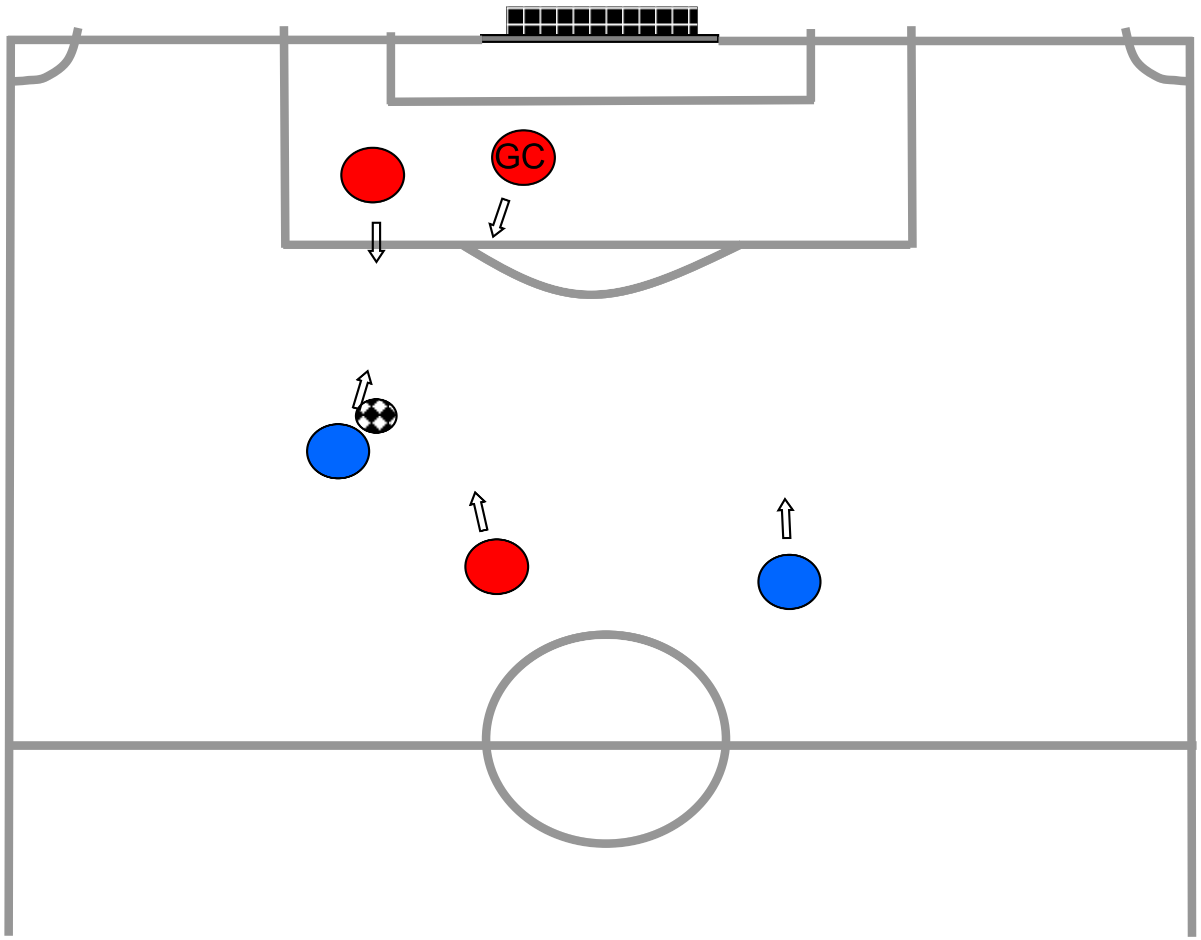

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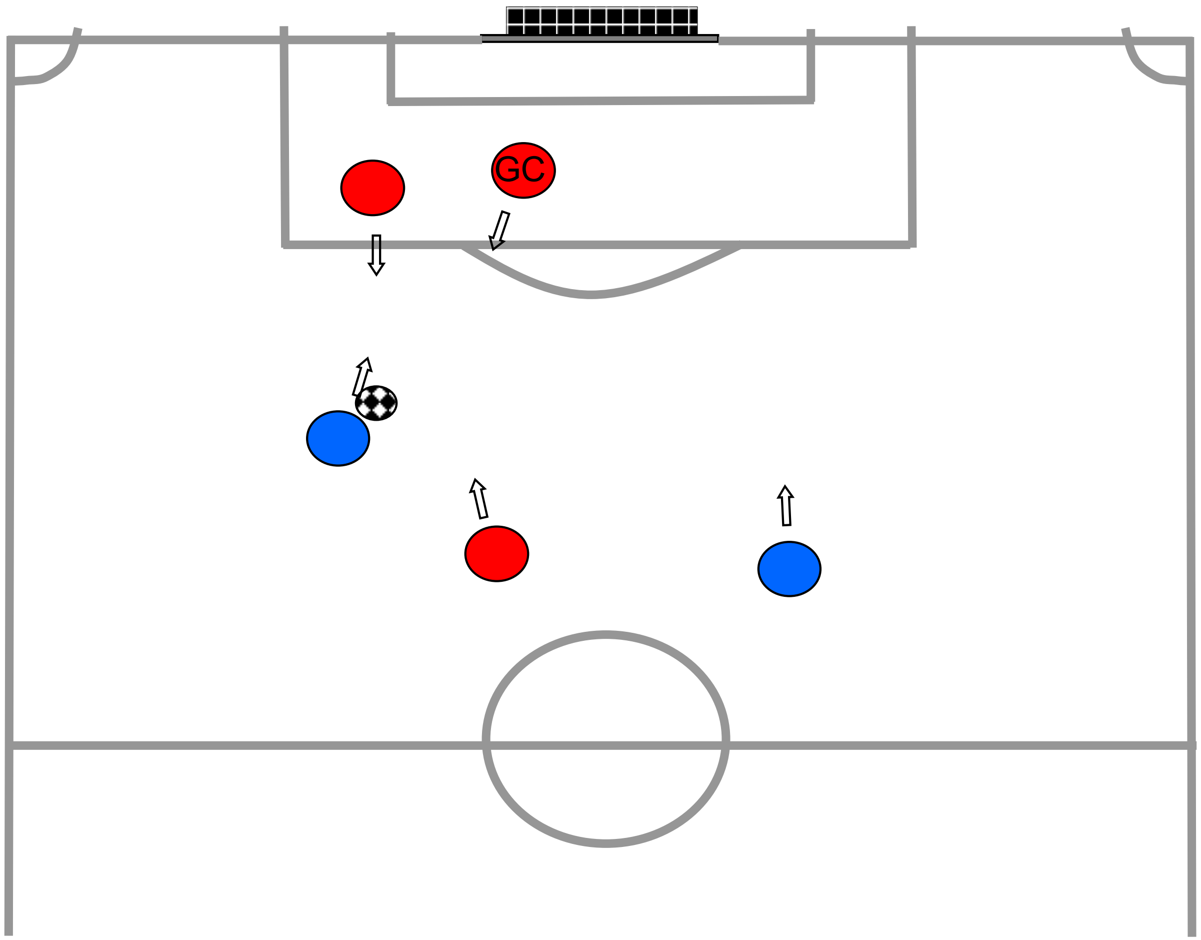
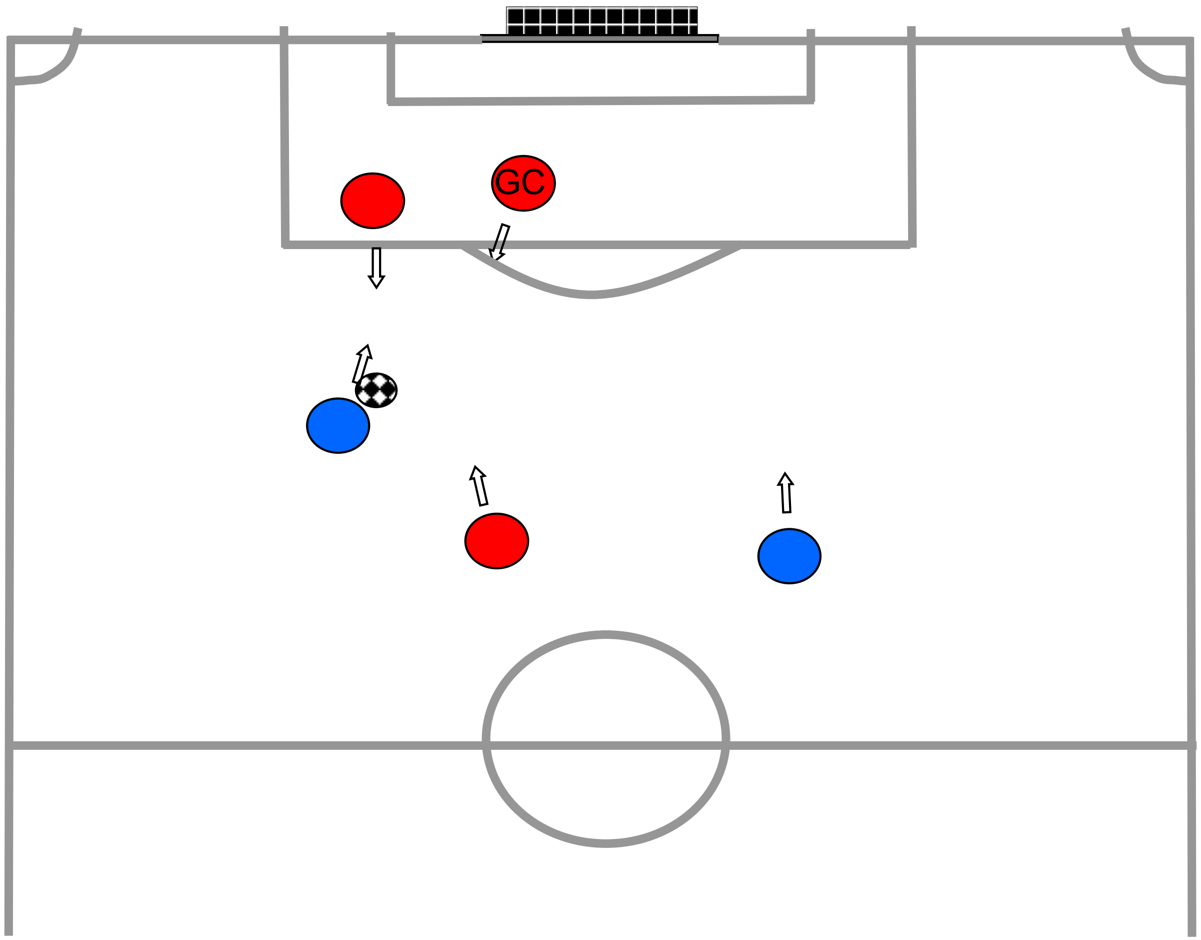


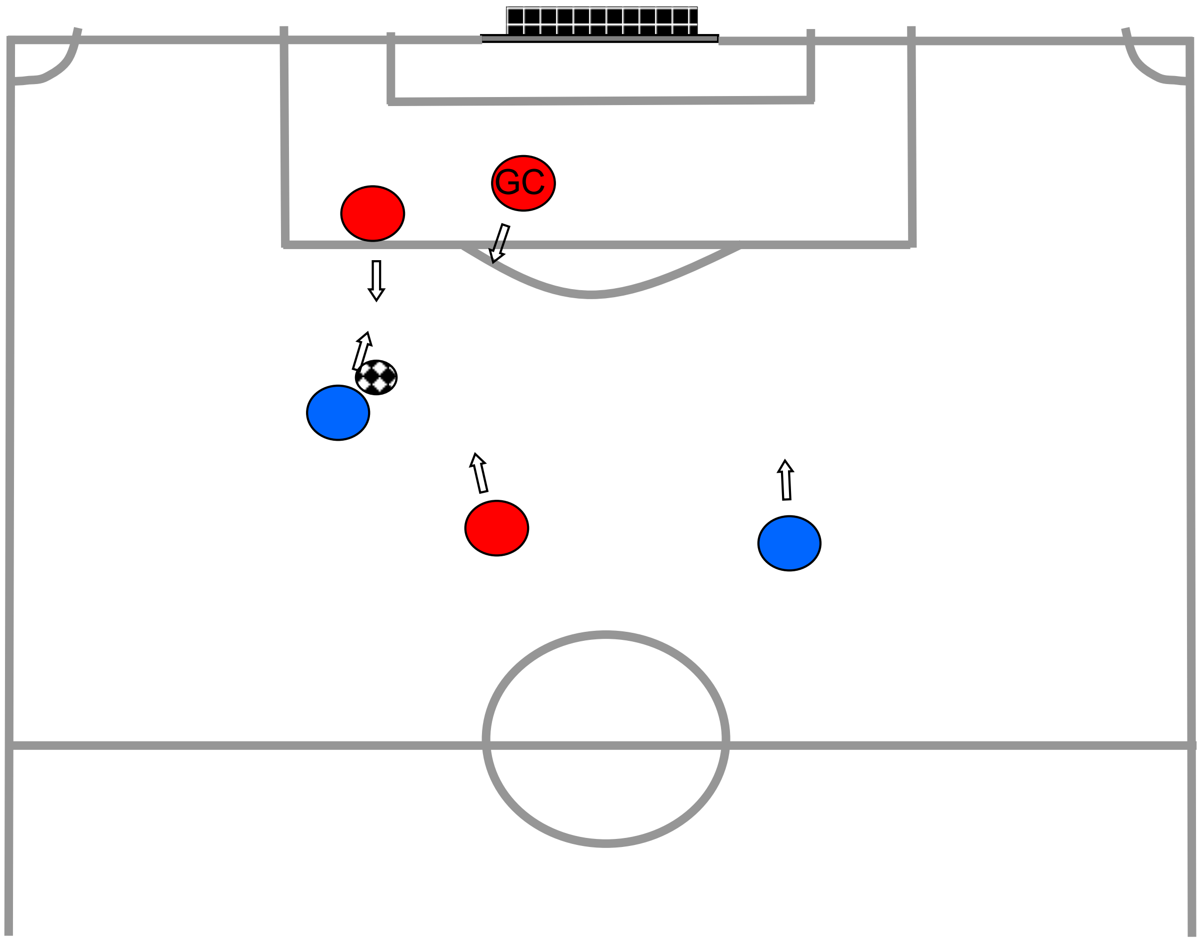
Recap from SMAI

… the defenders are closing in …



Recap from SMAI

What should you do?



Recap from SMAI

Problem solving

An autonomous agent

in some world

has a goal to achieve

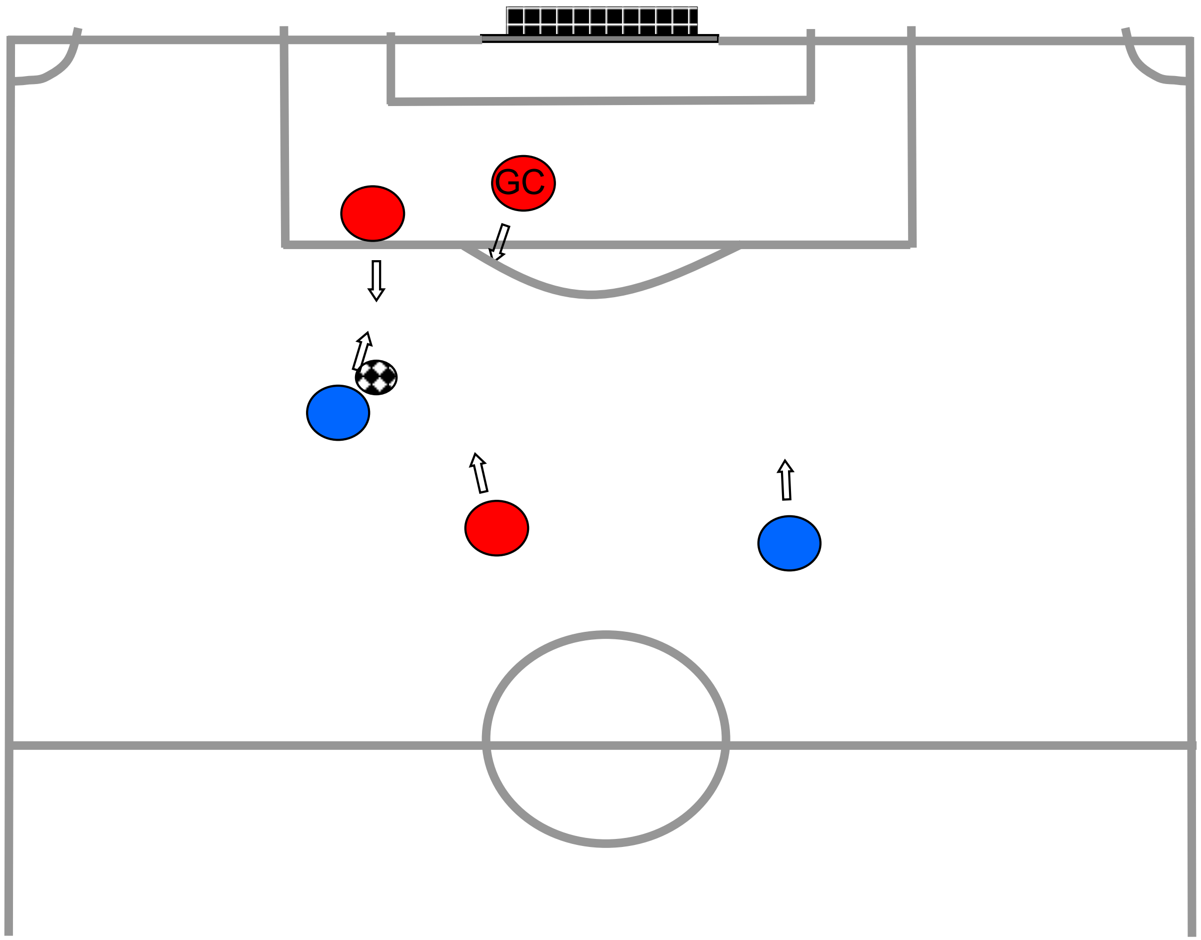
and

a set of actions to choose from

to strive for the goal

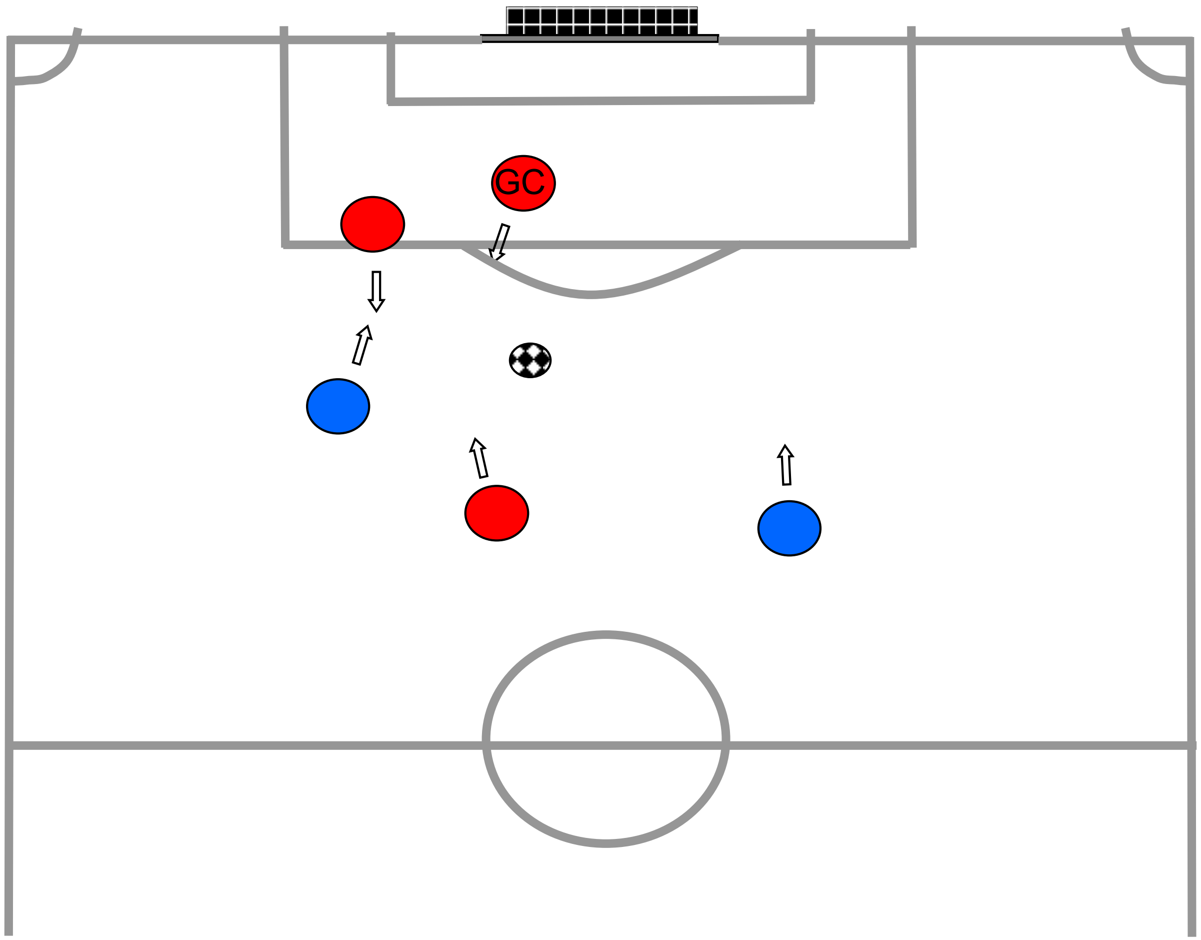
Recap from SMAI

An intelligent agent would…



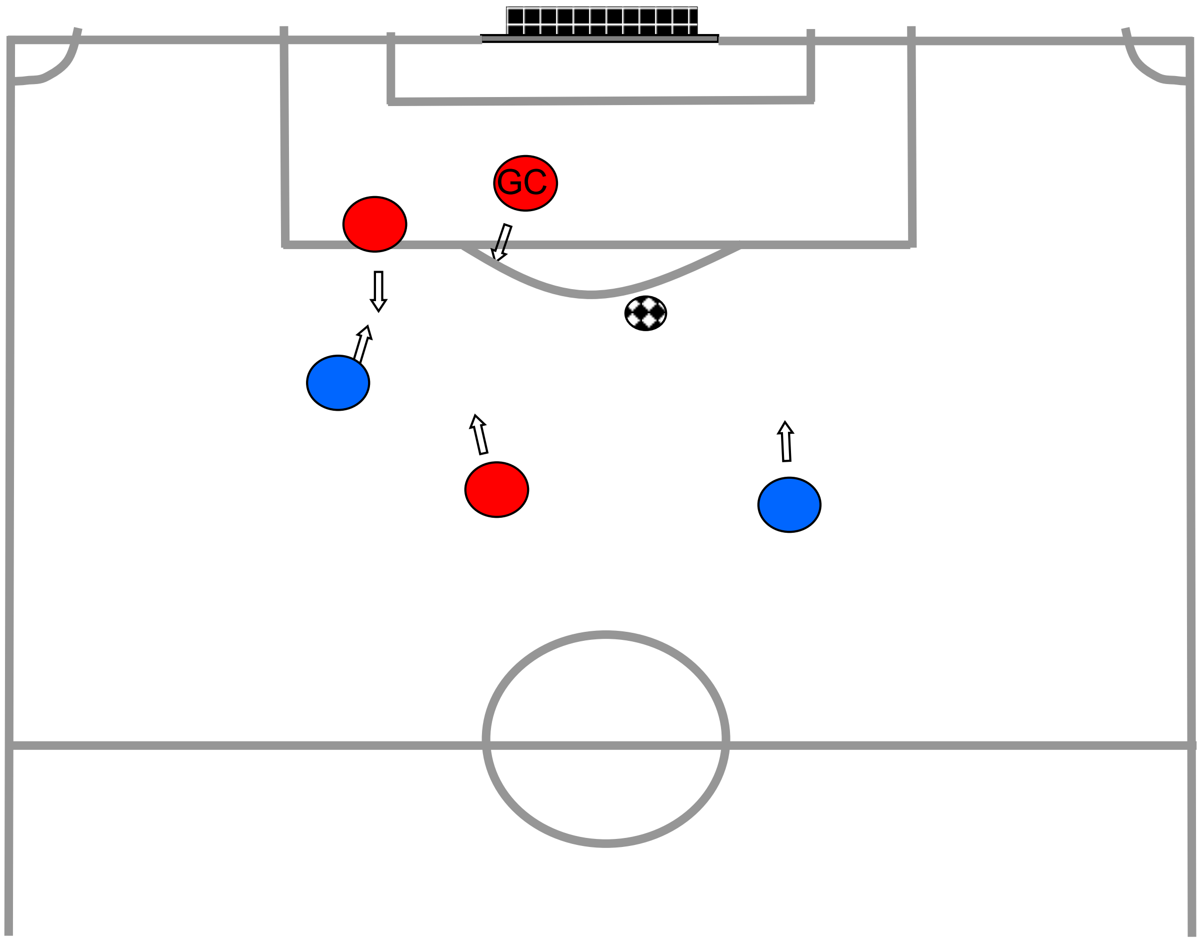
Recap from SMAI

Pass the ball to a teammate who is free…



Recap from SMAI

Pass the ball to a teammate who is free…



Recap from SMAI

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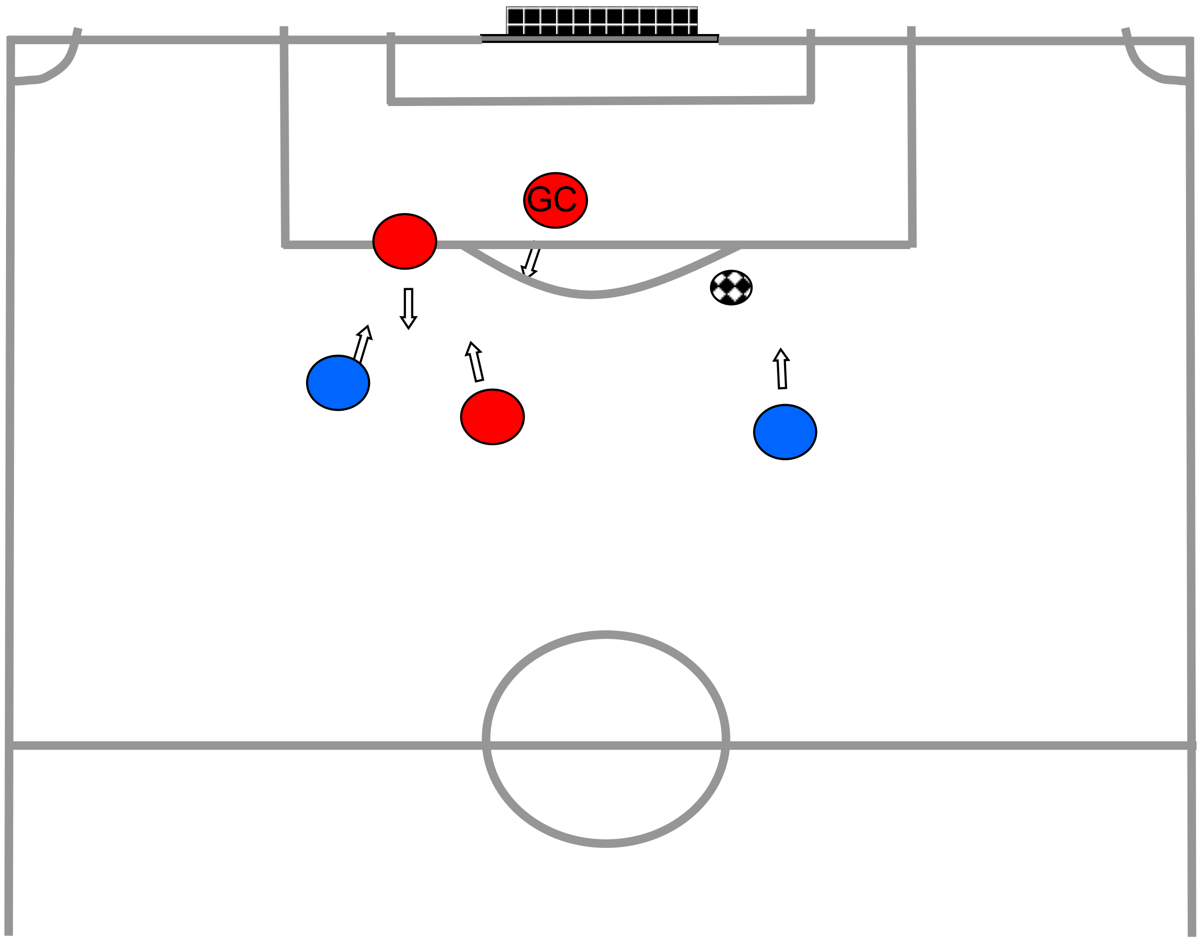
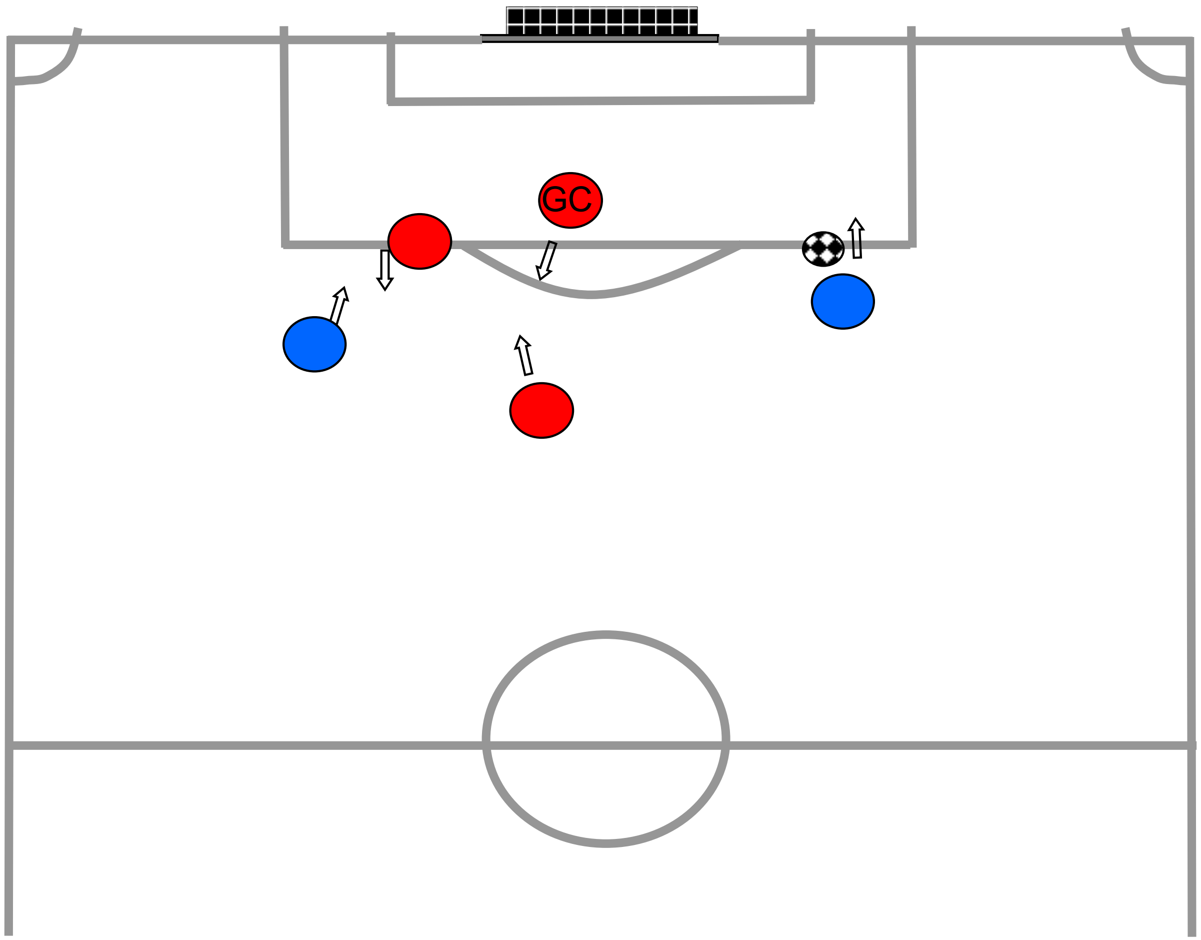


Recap from SMAI

… and has a better chance to score



Recap from SMAI

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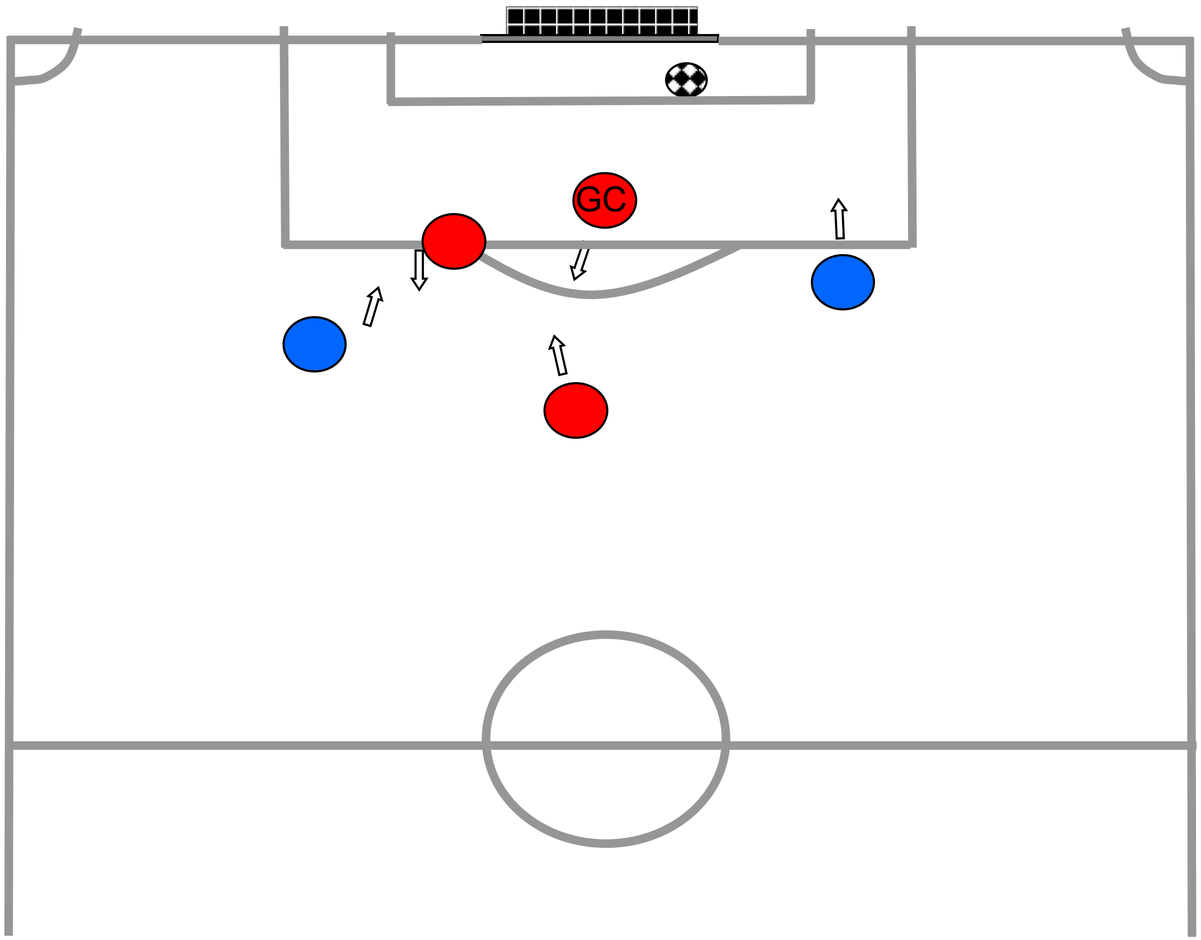

Recap from SMAI

Abductive Inferences

If you are running with the ball in a football game you must be (a) aware of where the other players *are* and (b) what they *intend* to do.

This inference of *intention* comes from background knowledge about the strategies and tactics used in the game – this knowledge comes from training.

You should be able to *imagine* that "if you kick the ball to where your teammate should be running to, then he would have a better shot at the goal".

The opponents no doubt are thinking about it too.
Why is the opposing team player running towards that spot?

Inferences

Inference is the basic cognitive act for intelligent minds.

We are constantly making inferences.

In the *The Myth of Artificial Intelligence* author Erik Larson says that most of the inferences we make as humans are abductive in nature.

Abduction is like guesswork, based on what we know about the world. Only, some people make more informed guesses than others.

Expectations

Abductive inferences generate expectations

On a football field

- what is the goalkeeper expected to do
- what about your teammate
- what are the opposing team players likely to do

Garden path sentences

- The old man's glasses…

…were filled with sherry

Jokes depend upon expectation violation

<u>An ocean of possible inferences</u>

Holmes and Watson are on a camping trip. In the middle of the night Holmes wakes up and gives Dr. Watson a nudge. "*Watson*" he says, "*look up in the sky and tell me what you see*.”

"*I see millions of stars, Holmes*," says Watson.

"*And what do you conclude from that, Watson?”*

Watson thinks for a moment. "*Well*," he says, "*astronomically, it tells me that there are millions of galaxies and potentially billions of planets. Astrologically, I observe that Saturn is in Leo. Horologically, I deduce that the time is approximately a quarter past three. Meterologically, I suspect that we will have a beautiful day tomorrow. Theologically, I see that God is all-powerful, and we are small and insignficant. Uh, what does it tell you, Holmes*?”

"*Watson, you idiot! Someone has stolen our tent*!”

— Thomas Cathcart, Daniel Klein

A short story

From "Identification of Conceptualizations underlying Natural Language" – Roger Schank

John meets Fred on the road. Fred has a knife. John is angry because his wife Mary has yelled at him…

Fred : Hi
John : What are you doing with the knife?
Fred : Thought I'd teach the kids to play mumbly-peg.
John : I could use a knife right now.
Fred : What's the matter?
John : Damn Mary, always on my back. She'll be sorry.
Fred : I don't think a knife will help you.
John : You're just on her side. I think I ought to . . .

… at this point the listener has some expectations

Expectations

Syntax	a verb
Meaning	a "conceptual structure" type and a filler for it
Context	the conceptual structure predicts an "action". Context delimits the range of possible actions, for example - end relationship, hurt someone, go to some place, emote
Conversational	people talk for a reason. To arouse sympathy, or to inform about intent, etcetra…
World view of listener	is John known to be a convicted murderer? The expectation would be different from if he were known to be an avowed pacifist.
Cultural norm	What is accepted within a culture?

What kind of knowledge structures in memory
would generate such expectations?

A short story

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Fred : I don't think a knife will help you.

John : You're just on her side. I think I ought to . . .

One would be considerably surprised to hear
" I think I ought to go and eat some fish"

Jokes exploit such violation of expectation.

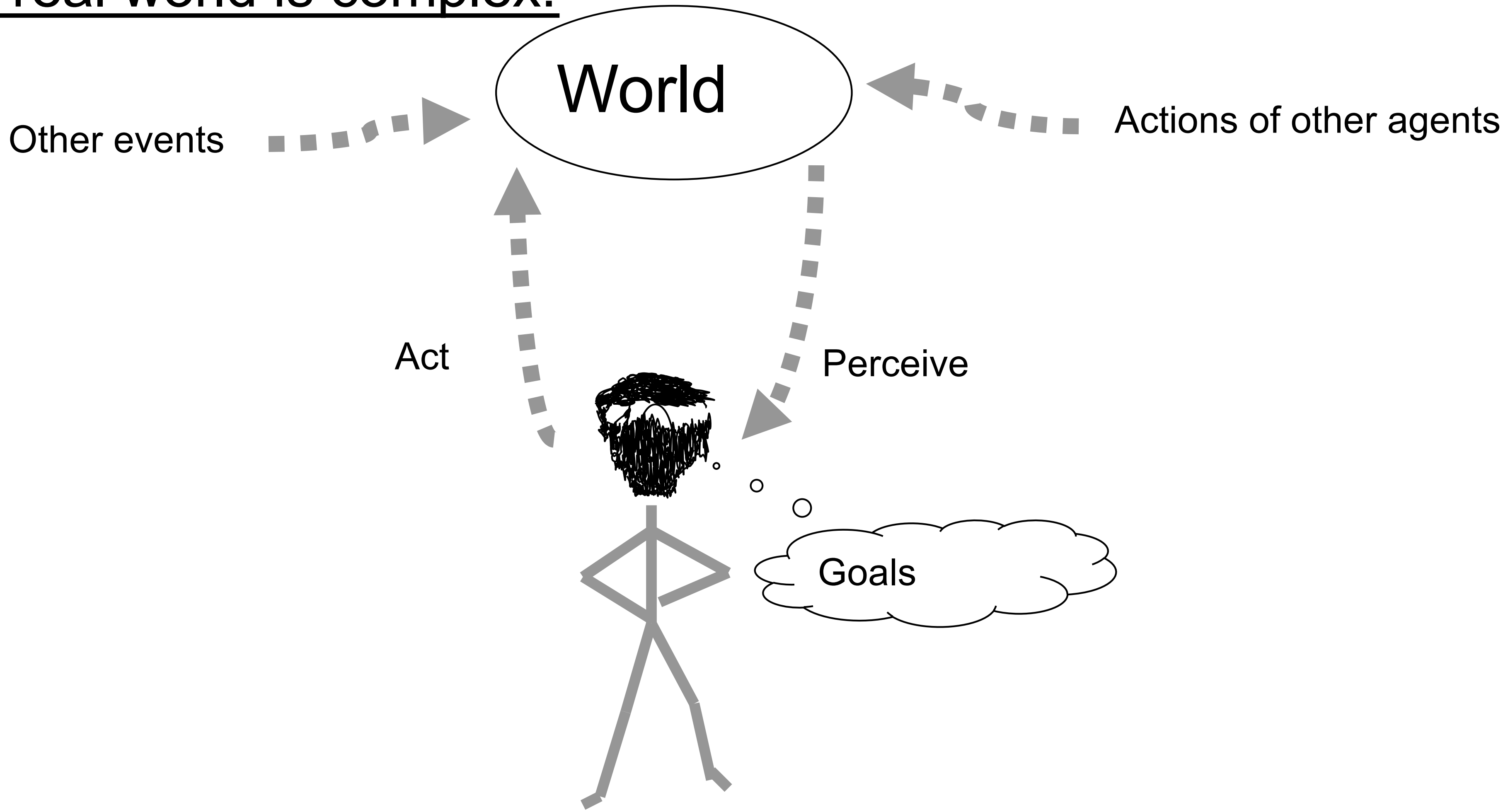
Scientific Progress

Scientific progress

- begins with abduction (looking for causes)
  - Why did the apple fall? Because gravity caused it
- and induction (making informed generalizations)
  - Fermat's Last Theorem
  - Goldbach's Conjecture
  - Beal's Conjecture

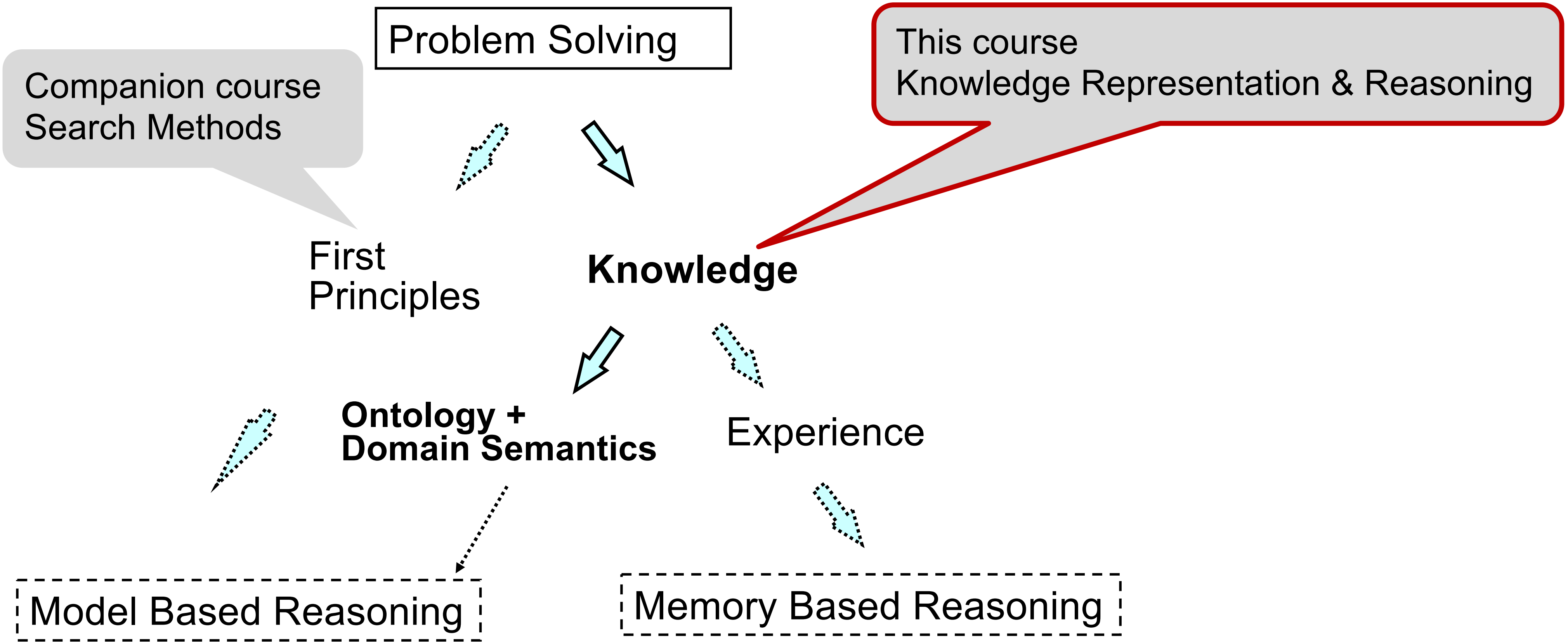
- and gets validated by deduction (making the implicit explicit)
  - Proof of Fermat's Last Theorem
- and experimental validation
  - light is bent by gravity
- Only induction adds new knowledge

The real world is complex!



Recap from SMAI

Humankind is a problem solving species

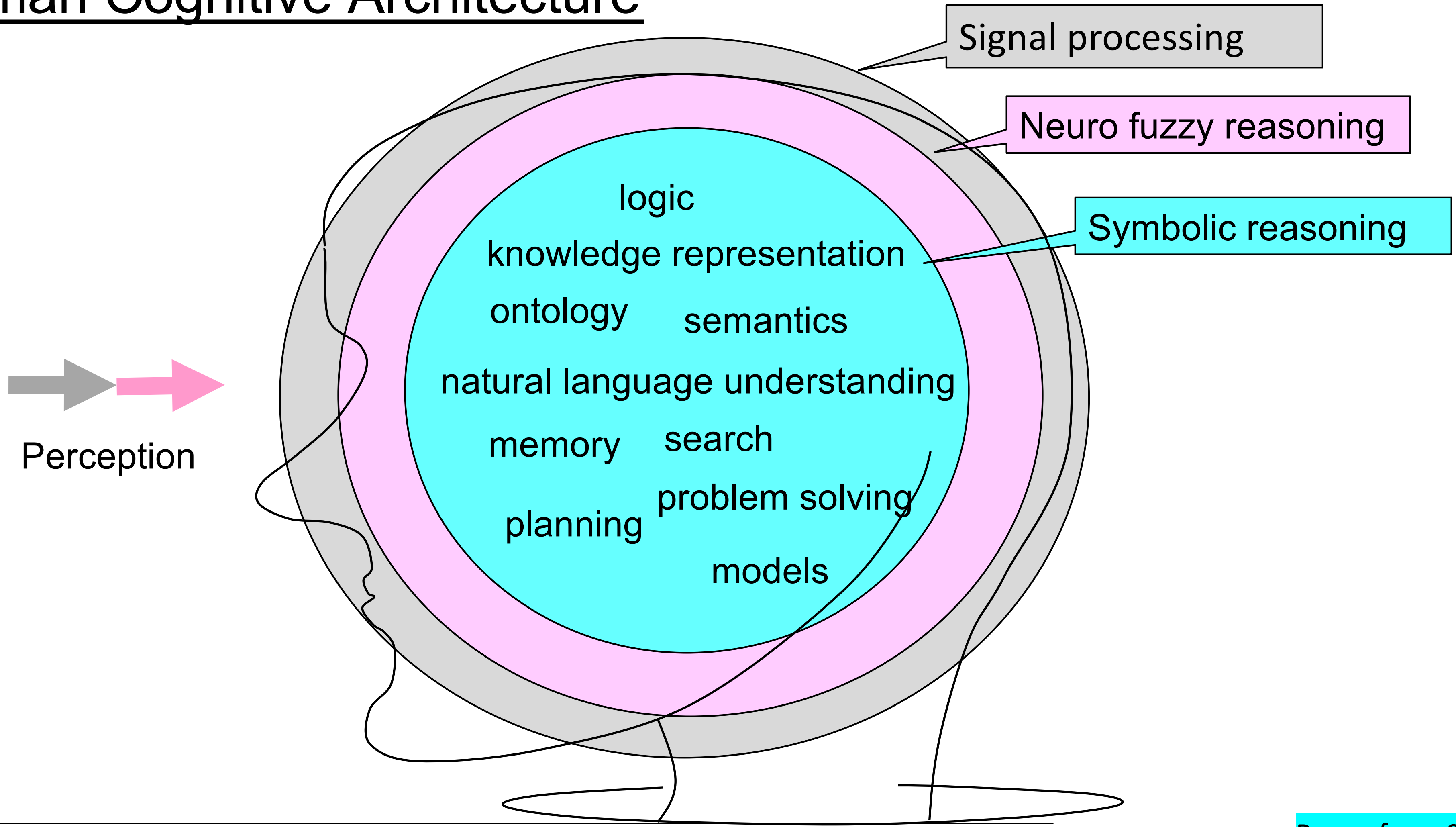


Artificial Intelligence & Machine Learning

- AI – symbolic knowledge representation and problem solving
- ML – making sense of data
  - Data → Information
    (big data, recomender systems, predictive analytics….)
  - Data → Classification
    (deep learning, images and language….)

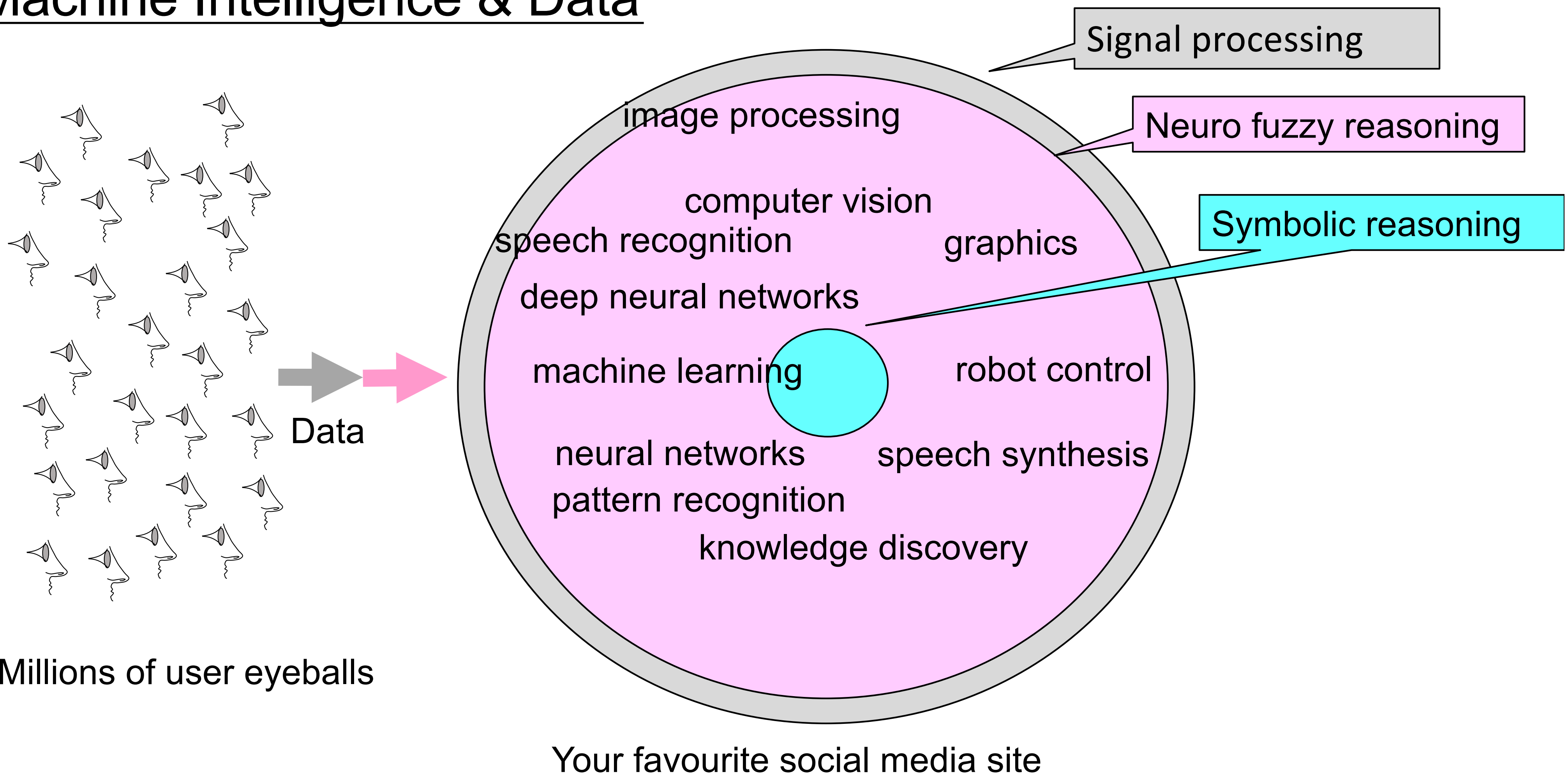
Recap from SMAI

Human Cognitive Architecture



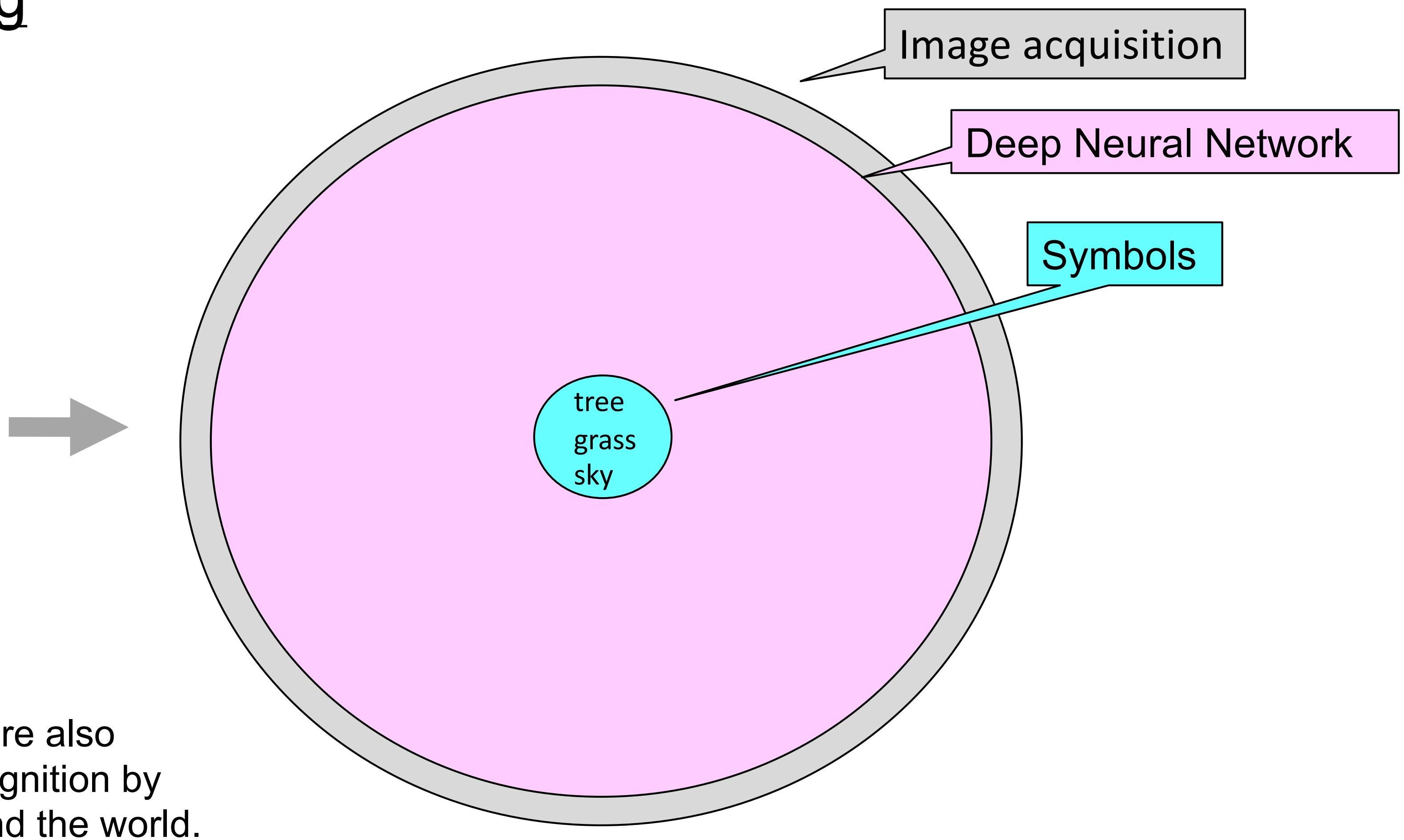
Recap from SMAI

Machine Intelligence & Data



Recap from SMAI

Image labeling



These algorithms are also used for facial recognition by governments around the world.

Recap from SMAI

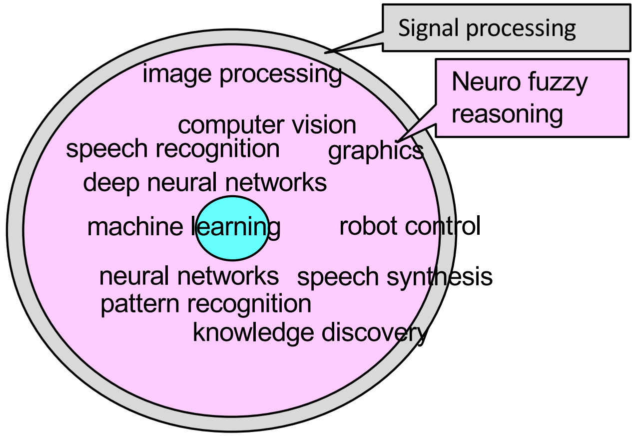
Animal–Like Abilities

“Everything ML does now,
humans do in the blink of an eye”

- “Eagles and snakes have better vision systems”
  - Judea Pearl
- Cats have superior navigation abilities
- Dogs recognize and react to human speech
- African grey parrots can mimic human speech

Yet, none of these animals have
the cognitive abilities and the intelligence
typically attributed to humans.

Adnan Darwiche, Human-Level Intelligence or Animal-Like Abilities,
CACM, Vol. 61, No. 10, Oct 2018.



Recap from SMAI

Performance vs. Competence

Now suppose a person tells us that a particular photo shows people playing Frisbee in the park. We naturally assume that this person can answer questions like *What is the shape of a Frisbee? Roughly how far can a person throw a Frisbee? Can a person eat a Frisbee? …*

Computers that can label images like "people playing Frisbee in a park" have no chance of answering those questions…

…they have *no idea* what a person is, that parks are usually outside, that people have ages, that weather is anything more than how it makes a photo look, etc.

Rodney Brook, The Seven Deadly Sins of AI Predictions.
MIT Technology Review

Recap from SMAI

Suitcase Words

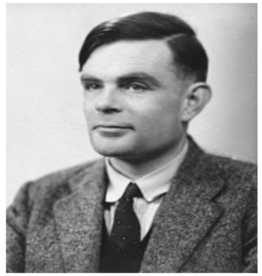
Marvin Minsky called words that carry a variety of meanings "suitcase words." "Learning" is a powerful suitcase word; it can refer to so many different types of experience…

When people hear that machine learning is making great strides in some new domain, they tend to use as a mental model the way in which a person would learn that new domain. However, machine learning is very brittle, and it requires lots of preparation by human researchers or engineers, special-purpose coding, special-purpose sets of training data, and a custom learning structure for each new problem domain.

Rodney Brook, The Seven Deadly Sins of AI Predictions.
MIT Technology Review

Recap from SMAI

Alan Turing's Imitation Game

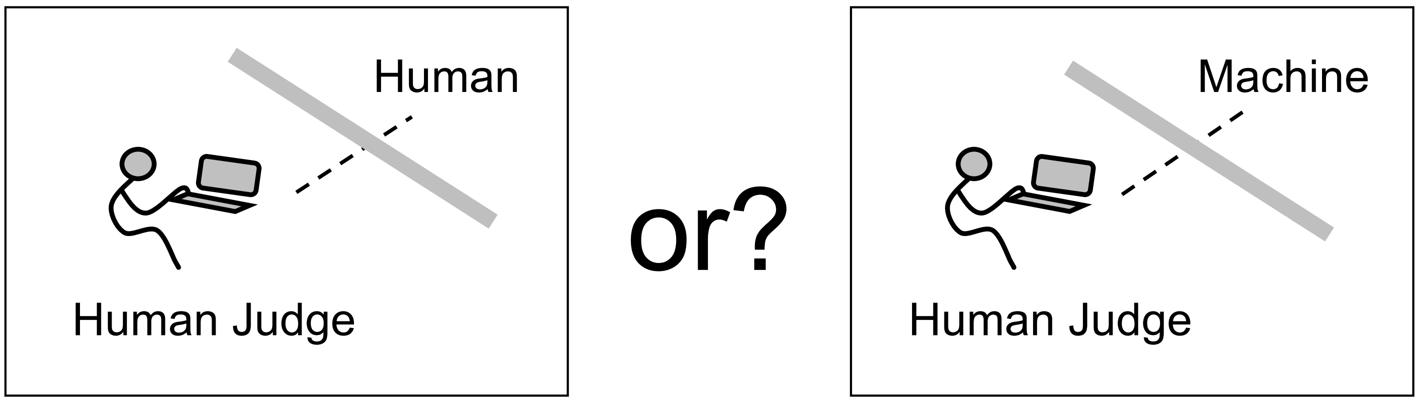


Alan Turing (1912 – 1954)

- The question whether machines can think
  is itself "too meaningless"

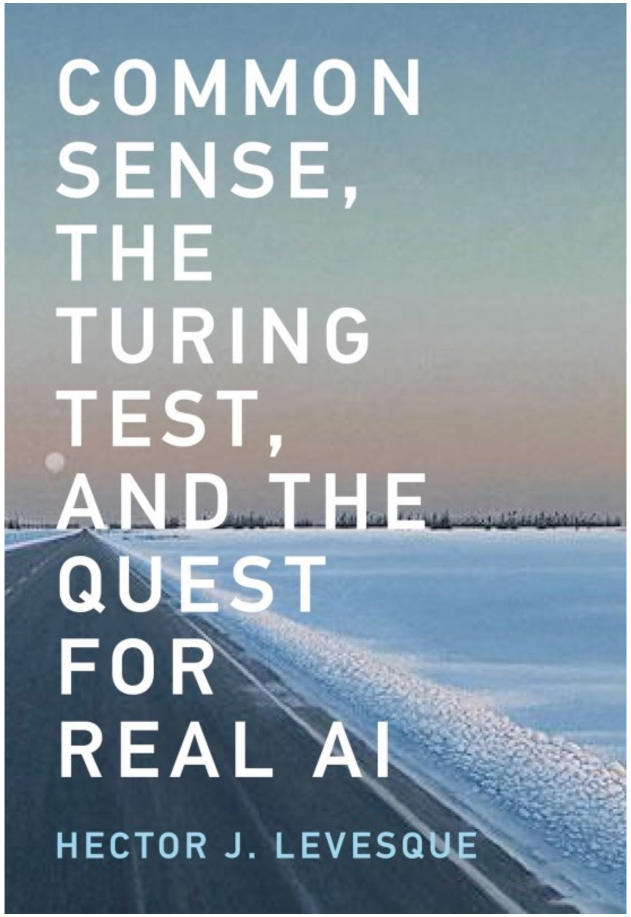
http://en.wikipedia.org/wiki/Alan_Turing

- Prescribed a test which he called the *Imitation Game* which is now known as *The Turing Test*
  - Turing, A.M. (1950). Computing machinery and intelligence. Mind, 59, 433-460. http://www.loebner.net/Prizef/TuringArticle.html



Recap from SMAI

Conversations with machines



Given the advances in web data processing, corpus based natural language processing,
and clever distracting techniques - it has become easy to build conversational chat bots that are impressive but lack intelligence.

Hector J. Levesque has recently proposed a new test.

Recap from SMAI

Winograd Schemas – an alternate "Turing Test"

- Winograd schemas ask a pointed multiple choice question that requires knowledge of the subject matter.

- For example, contexts where "give" can appear are statistically quite similar to those where "receive" can appear, and yet the answer must change depending on which one is used.

- This helps make the test *Google-proof:* having access to a large corpus of English text would likely not help much.

- The claim is that doing better than guessing requires subjects to figure out what is going on.

Recap from SMAI

Winograd Schemas: Anaphora Resolution

- A Winograd Schema Challenge question consists of three parts:
- A sentence or brief discourse that contains the following:
  - Two noun phrases of the same semantic class (male, female, inanimate, or group of objects or people),
  - An ambiguous pronoun that may refer to either of the above noun phrases, and
  - A special word and alternate word, such that if the special word is replaced with the alternate word, the natural resolution of the pronoun changes.
- A question asking the identity of the ambiguous pronoun, and
- Two answer choices corresponding to the noun phrases in question.
- A machine will be given the problem in a standardized form which includes the answer choices, thus making it a binary decision problem. https://en.wikipedia.org/wiki/Winograd_Schema_Challenge

Recap from SMAI

Winograd schema: Example 1

The first schema was given by Terry Winograd himself in 1972.
Such sentences are now named after him.

- The city councilmen refused the demonstrators a permit because they *feared* violence.

- The city councilmen refused the demonstrators a permit because they *advocated* violence.

Who does “they” refer to?

Answer 0: The demonstrators

Answer 1: The councilmen

Recap from SMAI

Winograd schema: Example 2 (IJCAI 2016 challenge)

- John took the water bottle out of the backpack so that it would be *lighter*.

- John took the water bottle out of the backpack so that it would be *handy*.

What does "it" refer to?

1. The backpack
2. The bottle

Recap from SMAI

Winograd schema: Example 3

- The trophy would not fit in the brown suitcase because it was too *small*.
- The trophy would not fit in the brown suitcase because it was too *big*.

What does “it” refer to?

1. The trophy
2. The suitcase

Recap from SMAI

Winograd schema: Example 4

- The lawyer asked the witness a question, but he was reluctant to *repeat* it.
- The lawyer asked the witness a question, but he was reluctant to *answer* it.

Who was reluctant?

1. The lawyer
2. The witness

Recap from SMAI

Representation

ontology

noun: **ontology**; plural noun: **ontologies**

1.1. the branch of metaphysics dealing with the nature of being.

2.2. a set of concepts and categories in a subject area or domain that shows their properties and the relations between them.

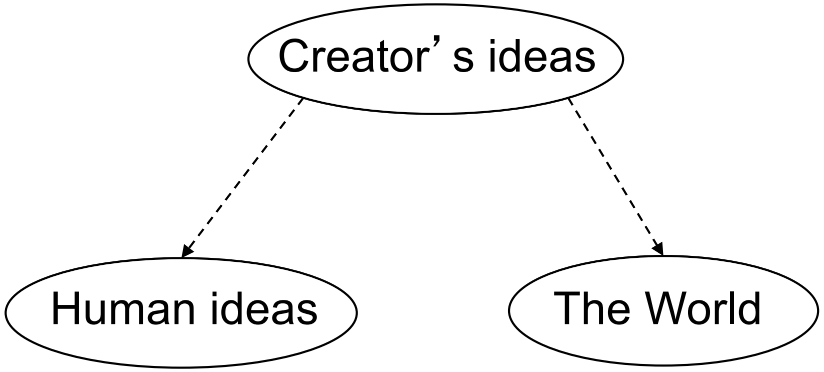
Ontology: *An explicit specification of a conceptualization*.
(Gruber, 93)

The emergence of the mind in philosophy

The European medieval world view

A Christian adaption of Greek ideas

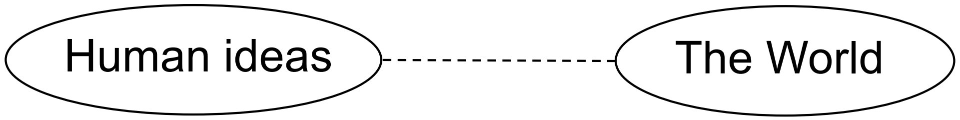
Platonic



Corruptible materializations of God's ideas

Our thoughts are *true* to the extent they are accurate copies of God's ideas

Aristotelian



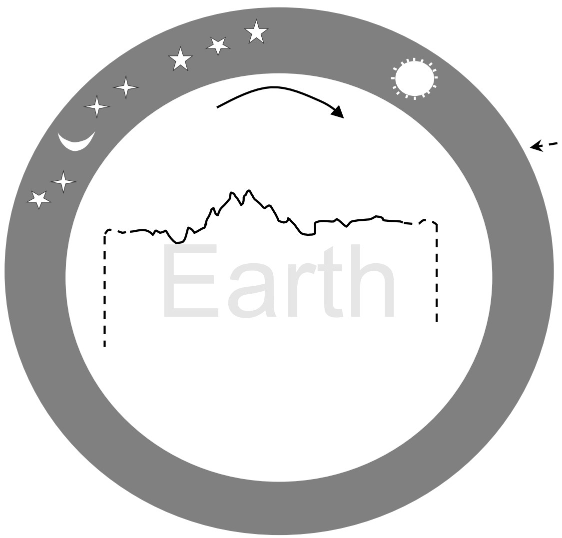
Our thoughts *resemble* the objects they stand for

Correspondence theory of truth

… Ludwig Wittgenstein: Picture Theory of Language

Recap from SMAI

Our world as we saw it



Our Earth was flat and at the center of the Universe, with the God's heaven rotating around it.

Sensible world composed of 5 elements

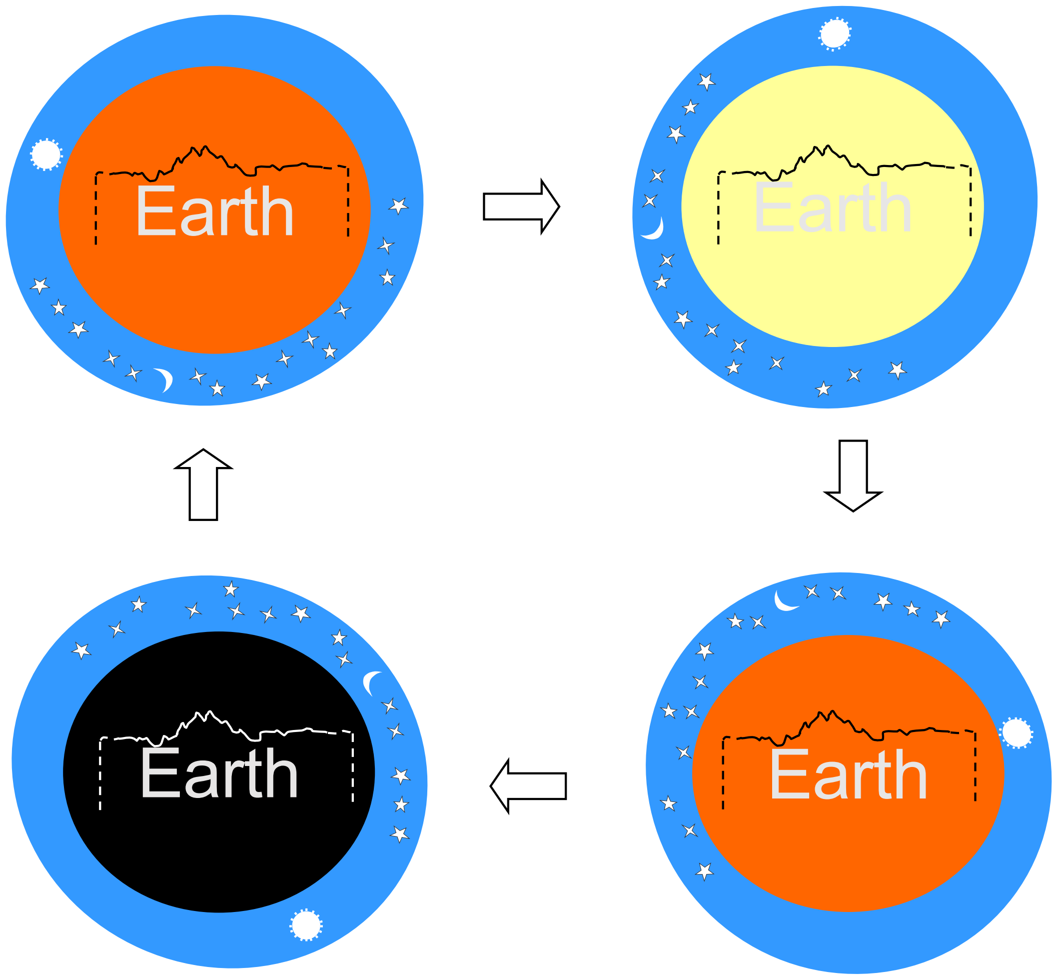
- quintessence
- fire
- air
- water
- earth

heavier

Jumbled up on Earth striving to separate and go their rightful place

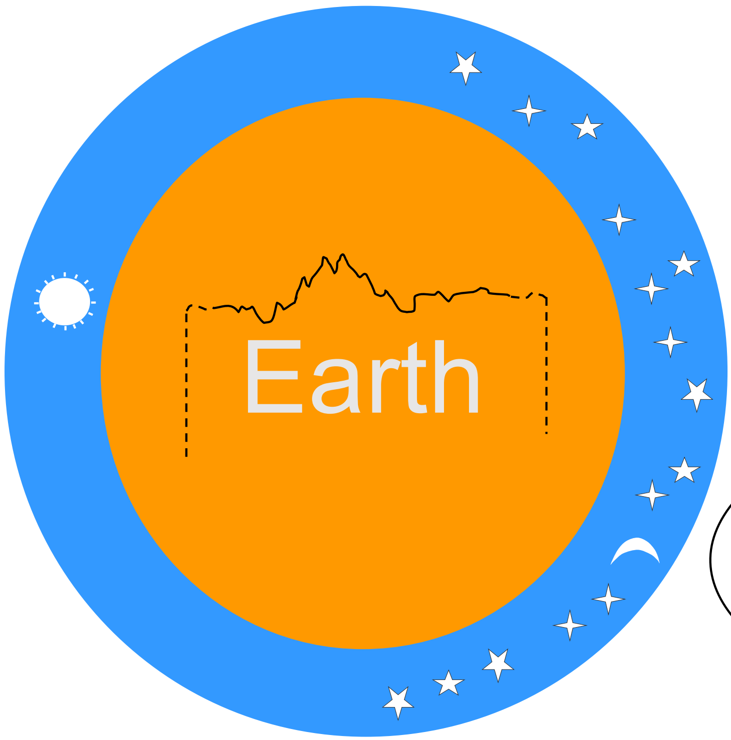
Recap from SMAI

Night & Day



Recap from SMAI

Geocentric model of the Universe



Astronomy was the most advanced empirical science, and observations like the **motion of planets** in the sky was specially **hard to explain** with the geocentric model.

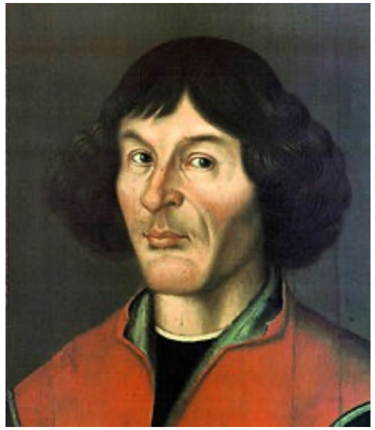
"If God had consulted me when creating the universe, He would have received good advice!"

King Alfonso X of Spain (1221 – 1284)

Recap from SMAI

What we see is not what really is…

It is the rotating Earth that creates the illusion of the Sun, the moon and the stars moving in the sky. (*On the Revolutions of the Celestial Spheres*)



Nicolaus Copernicus
Portrait, 1580, Toruń Old Town City Hall
Born 19 February 1473
Toruń (Thorn), Royal Prussia,
Kingdom of Poland

Source: http://en.wikipedia.org/wiki/Nicolaus_Copernicus

Recap from SMAI

Reality

What is **really** out there?

What is the **objective reality?**

One thing is clear

Everything in the physical world is made up of a small number of fundamental particles

(even though we don't quite know yet what they are)

unless there is no matter at all (idealism)

The laws of physics that explain the behaviour of these particles are sufficient to explain the behaviour of ensembles of such particles

But…

Recap from SMAI

Complexity

A human adult is made up of about 10^{27} atoms

These 10^{27} atoms continuously interact with zillions of surrounding atoms all the time

The air we breathe, the food we eat, the vibrations of air molecules we *sense as sound,* and impinged upon by trillions of photons (which have momentum but no mass).

Can we even hope to write down equations for these and solve them?

And what would we get if we did solve them?
A prediction of their location and movement?

Remember there are 10^{27} of them

Recap from SMAI

The World in our Minds

The world around us and including us operates according to and can, in principle, be explained by the fundamental laws of physics. Nothing else is needed.

But we the thinking creatures create our own worlds in our minds. And it is only our own creation that is meaningful to us.

Idea embodied in movies: Matrix, Inception…

Recap from SMAI

Powers of Ten

A Film by Charles and Ray Eames (1977)
http://www.powersof10.com/film

Source: Quarks to Quasars
http://www.wordwizz.com/pwrsof10.htm

100 yottameter – 10^{26} meters – The Visible Universe (about 10 billion light years across)
1 yottameter – 10^{24} meters – a cluster of galaxies (about 100 million light years across)
1 zettameter – 10^{21} meters – diameter of The Milky Way (about 100,000 light years across)
100 petameters – 10^{17} meters – the nearest stars (about 10 light years away)
10 terameters – 10^{13} meters – diameter of Solar system (11,826,600,000 km)
1 terameter – 10^{12} meters – distance from Saturn to Sun (1,429,000,000 km)
100 gigameters – 10^{11} meters – distance from Earth to Sun (149,600,000 km)
100 megameters – 10^{8} meters – the diameter of Jupiter (139,822 km)
10 megameters – 10^{7} meters – the diameter of Earth (12,756 km)
1 megameter – 10^{6} meters – the distance from Chennai to Pune (1190 km)
100 kilometers – 10^{5} meters – the distance from Mandi to Manali (110 km)
10 kilometers – 10^{4} meters – the diameter of a small town
1 kilometer – 10^{3} meters – longest span of the Golden Gate Bridge (1,280 m)
100 meters – 10^{2} meters – a sprint track, a meadow, a pond, a skyscraper
10 meters – 10^{1} meters – the width of a road, a small house, a tree
1 meter – 10^{0} meters – a typical door, a table, the height of a child
10 centimeters – 10^{-1} meters – a sunbird, a typical mango, a cellphone
1 millimeter – 10^{-3} meters – a mustard seed
100 micrometers – 10^{-4} meters – pollen
10 micrometers – 10^{-5} meters – a bacterium
100 nanometers – 10^{-7} meters – a virus
1 nanometer – 10^{-9} meters – the structure of DNA
100 picometers – 10^{-10} meters – carbon's outer shell – 1 Angstrom unit
1 picometer – 10^{-12} meters – the electron cloud – electromagnetism
10 femtometers – 10^{-14} meters – the carbon nucleus
1 femtometer – 10^{-15} meters – a proton
10 attometers – 10^{-17} meters – quarks and gluons

Recap from SMAI

Our Perceptible Universe

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100 kilometers – 10^{5} meters – the distance from [illegible] to Manali ([illegible]10 km)
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Scientific progress enables us to extend our concepts to different scales

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Recap from SMAI

Domains of Study: Each has its own vocabulary

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Cosmology
Astronomy
Astrophysics
Newtonian physics
Geography
Geology
Sociology
Economics
Psychology
Newtonian physics
Physiology
Biology
Cellular biology
Chemistry
Sub-atomic physics

Recap from SMAI

Downward Causality: How thought controls action

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100 nanometers – 10^{-7} meters – a virus
1 nanometer – 10^{-9} meters – the structure of DNA
100 picometers – 10^{-10} meters – carbon's outer shell – 1 Angstrom unit
1 picometer – 10^{-12} meters – the electron cloud – electromagnetism and gravity
10 femtometers – 10^{-14} meters – the carbon nucleus
1 femtometer – 10^{-15} meters – a proton
10 attometers – 10^{-17} meters – quarks and gluons

We **operate** with **concepts** at our perceptible level. Our **thoughts** at this level **cause** the lower level activity that results in our **actions**

Douglas Hofstadter in "*I am a Strange Loop*"

Recap from SMAI

Epiphenomenon in computers

Computers are man made objects. We know how they operate. At the very core the computer does only bit level operations.

Everything else is built upon that, and everything can be explained by that.

But how does a lay user see the machine? A music player, a web browser, a video player, a word processor, a keeper of facts, an accounting spreadsheet.

In other words a Universal Machine (a machine that can imitate any other machine). Can this machine become intelligent?

Yes, if it can introspect and examine itself
and has access to an endless possible set of concepts
– Douglas Hofstadter in *I am a Strange Loop*.

The Domains for Reasoning

While the real world that we want to reason about is indeed made up of collections of fundamental particles,
those fundamental particles, whatever they are,
cannot be the elements of the domain
that we use for representation and reasoning.

This is simply because there are far too many of them,
even to describe a grain of rice.

Instead, depending upon the focus of study,
one can represent atoms, or molecules, or biological cells,
or animal organs, or living creatures,
or societies of living creatures.

Every domain of study defines it own ontology.

The Choice of Predicates

- The logic community is focused on proofs
  - On Soundness, Completeness, Consistency and Decidability
- Logicians work with arbitrary predicates
  - They invent predicate names as and when needed
  - Usually some word from the English, or any other natural language
  - But natural languages are rich
  - The same thing can be said in many ways
  - Loves(a, b), Adores(a,b), DotesOn(a,b), InLoveWith(a,b)…
- Choosing predicates arbitrarily *necessitates* adding rules which work on the predicates
  - An explosion in the number of rules!
  - And in the complexity of theorem proving algorithms

Choosing predicates

- The domain D of first order logic is a set of individuals
- The predicates of FOL capture
  - relations between individuals. For example, Friend(sumedha, shreya)
  - categories or concepts. For example, Man(socrates)
  - relations between categories. For example, $\forall x$ (Deer(x) $\supset$ Mammal(x))
  - relations between named relations. For example, $\forall x,y$ (Brother(x, y) $\supset$ Sibling(x, y))
- Inferences involve traversing from the known (explicit) to the unknown (implicit)
- Rules of inference facilitate this traversal
- The more the number of predicates the more the rules
- What should be the set of predicates in a domain?
  - to make the representation compact and canonical
  - to avoid a tsunami of rules and inferences
  - English verbs and and adjectives are far too many!

Closed Worlds and Open Worlds

Do we know the world completely? Or is our knowledge incomplete?

The closed world assumption says that
what you know is *all* there is to know about the world.

This implies that if you do not know something, it is false.

The open world assumption says we have
only *partial* knowledge of the world around us.

This implies that we may not know if a statement is true or false.

Domain: A set of Individuals

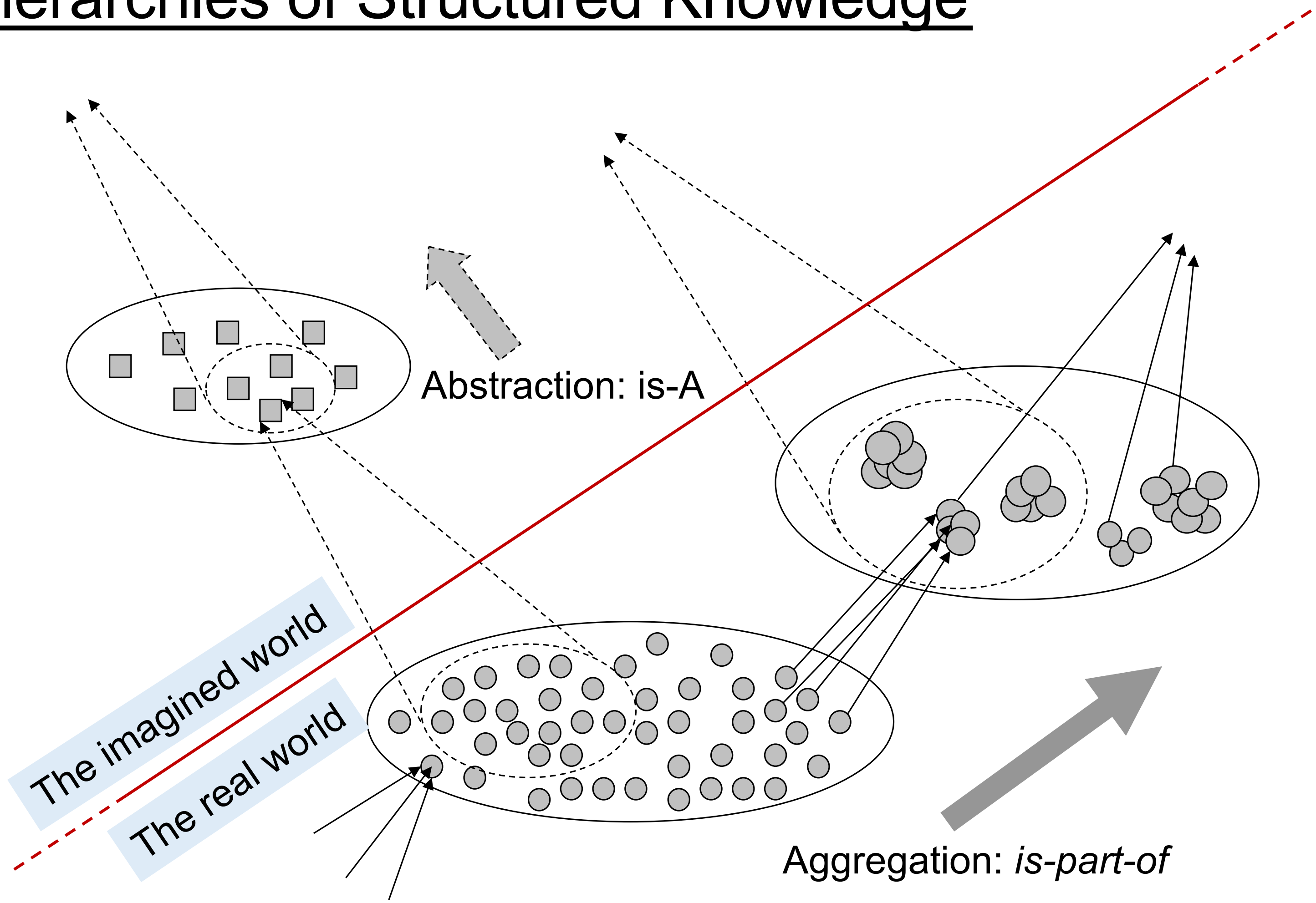
- From the perspective of logic the domain is a set of individuals and predicates define relations between the individuals
- From the perspective of knowledge representation the question is what should those individuals in the domain be?
- We cannot represent the physical world as seen by physics
  - that is made of of some fundamental particles
- We need to represent concepts in our cognitive models
  - A person, for example, Socrates.
  - But if Socrates is an individual in the domain
    what about the right hand of Socrates?
  - Is the right hand another individual? What about his index finger?

- What about concepts like water, air, and sky?

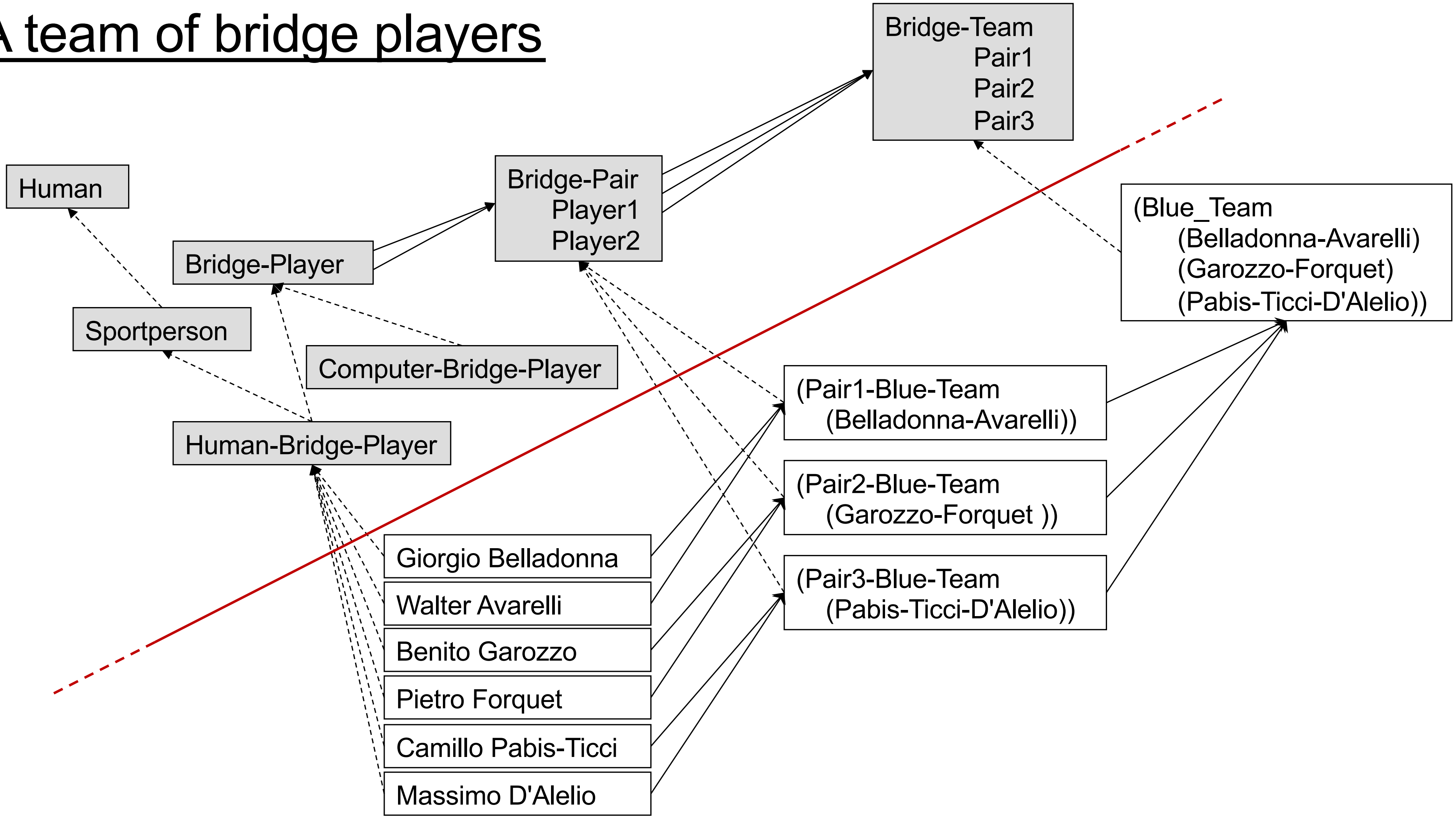
Aggregation and Reification

- The individuals in our cognitive models are not the individual elements in the domain – which are the elementary particles
- Instead we invent *our own concepts* in our heads
  - people, trees, dogs, nations, organizations, football teams, governments, rivers, parks, shopping malls, shops, cars, trains, bicycles, cakes, bread, cities, galaxies, protein molecules.
  - we also think of concepts like length and colour.
  - these are all abstract or reified composites that *we think of* as individuals.
  - when we say “the rose is red” we mean an individual rose
  - but when we say “violets are blue” we mean categories
  - we also think of time, events, actions
- We also think of entities like air, water, and sky
  - but it is not clear whether they are individuals
  - or even categories
  - What does a “glass of water” represent?

Hierarchies of Structured Knowledge



A team of bridge players



Beyond categories and concepts

The language of logic is concerned with sentences.

A sentence is something that is either true or false (whether we know the truth value or not). For example,

- Roses are red, and violets are blue.
- A blade of grass contains information of the entire world.
- A butterfly flapping its wings in Brazil can cause a storm in Texas.

But knowledge about the world goes beyond simple sentences.

Complex organisms can be described only by collecting a large number of sentences and organizing them into meaningful structures.

Situational Knowledge

Consider the following observation:

"Anisa walked into the bookstore"

- That is a fact that you *know*. What can you infer from this?
- If you know about bookstores…
  - Anisa will probably browse through the books
  - Or look for a specific one
  - Perhaps she will go to the counter and pay for it
  - She may emerge with a book in hand
- If you *know* that Anisa is the sister of the owner
  - Maybe she was just passing by and wanted to meet her.
  - Maybe she is going to sit in for the owner for a while.
  - Maybe she is also looking for a specific book.
- Maybe she had a gun and wanted to rob the store?
  - If she lives in a country where it is common to carry guns.

Knowledge Structures

- How does one represent knowledge about bookstores?
- Or about restaurants, or about dental clinics?

- In some sense we collect and organize individual bits of facts about the typical knowledge about these entities
- Aggregated representations
- Roger Schank called such structures *Scripts*
- Marvin Minsky called them *Frames*
  - And gave rise to the idea of Object Oriented Programming Systems

- If you are blindfolded and touching something
  how can you guess that it is an elephant?
  - You have to know about elephants in the first place

Taxonomies

- One approach to representing knowledge would be to have a large pool of sentences
- An algorithm for making inferences would search through the sentences to make the right connections
- This would be at the cost of computational complexity
- Instead we tend to organize facts into taxonomies
- Taxonomies facilitate inheritance
  - For example, mammals have two eyes
  - Implies that cats have two eyes
- Taxonomies facilitate compactness
  - We only need store a property in a super class
  - And inherit it into a subclass
- Minsky’s frames led to OOPs

A quick tour of logic languages

Propositional Logic

Which of the arguments are valid arguments?

- If the earth were spherical, it would cast curved shadows on the moon. It casts curved shadows on the moon. So it must be spherical.

- If he used good bait and the fish weren't smarter than he was, then he didn't go hungry. But he used good bait and he did go hungry, **SO** the fish must have been smarter than he was.

First Order Logic

One of Tinker, Tailor, Soldier, or Spy is the culprit. The culprit stole the document. Tinker and Soldier did not steal the document. If Tailor or Spy is the culprit, then the document must be in Paris.

Given the above facts show that the following sentence is true

"The document is in Paris."

Notion of variables and quantifiers over variables

Timeless, changeless, a logic of relations
between elements of sets

Description Logics

A progressive high tech company is one with at least five women on its board of directors and one in which all the employees have technical degrees where the minimum salary is 100000.

A tech company is one all whose employees have technical degrees.

A progressive high tech company is a tech company.

A family of *logics of noun phrases*

The formal basis of ontologies

Default Reasoning

If Tweety is a bird then one can conclude that Tweety can fly,

because even though there exist birds, for example the ostrich, that cannot fly, in *general* most birds fly.

In the real world an intelligent agent has to make inferences even with incomplete information. In such a scenario one has to make use of what is generally true in a typical scenario.

New information may contradict and defeat the default conclusion.

The Event Calculus

Jogesh made a cup of tea and left it on the table. Meanwhile Smita saw the cup of tea and drank it. When Jogesh came back he saw that the cup was empty.

Reasoning about time, action, and change.

Epistemic reasoning

Jogesh made a cup of tea and left it on the table. Meanwhile Smita saw the cup of tea and drank it. When Jogesh came back he saw that the cup was empty.

He concluded that Smita had polished off his cup of tea.
Smita knew that Jogesh knew that she drank the tea.

Knowledge and belief of agents

Syllabus

Logic and Languages

Soundness and Completeness

Propositional Logic

Tableau Method

Representation

Direct Proof

First Order Logic

Reification

CD Theory

Frames and Scripts

Forward Chaining

Rete Net

Taxonomies

Backward Chaining

Inheritance

Description Logics

Logic Programming

Resolution Refutation

RDF and OWL

Prolog

Default Reasoning

Circumscription

Event Calculus

Epistemic Logic

We begin with the relation between

Symbols and Thought