Representing and Reasoning About Contexts

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Outline

1. Contexts in natural languages

Literally, a context is text that accompanies a text. More generally, the context may be any background knowledge, physical or verbal, that helps explain a text. Natural languages are highly flexible, expressive, and context dependent. These properties make them easy to use by people, but difficult to analyze and reason about in computer systems.

2. Situation semantics

Situation semanatics (*Barwise and Perry 1983*) *is a version of context theory that was developed at Stanford* (*CSLI*)*. The ideas can be adapted to other versions of logic, including Common Logic and IKL.*

3. Representing contexts in logic.

Various logics have been used to represent contexts. This section uses the IKL extensions to common logic. But similar methods have been used with other versions of logic.

1. Context in Natural Languages

Human language is based on the way people think and talk about everything they see, hear, feel, do, and remember.

Ambiguities can be resolved by three kinds of context: the current discourse, the current situation, and any past memory.

Ambiguity in word senses: ***My dog bit the visitor's ear*.**

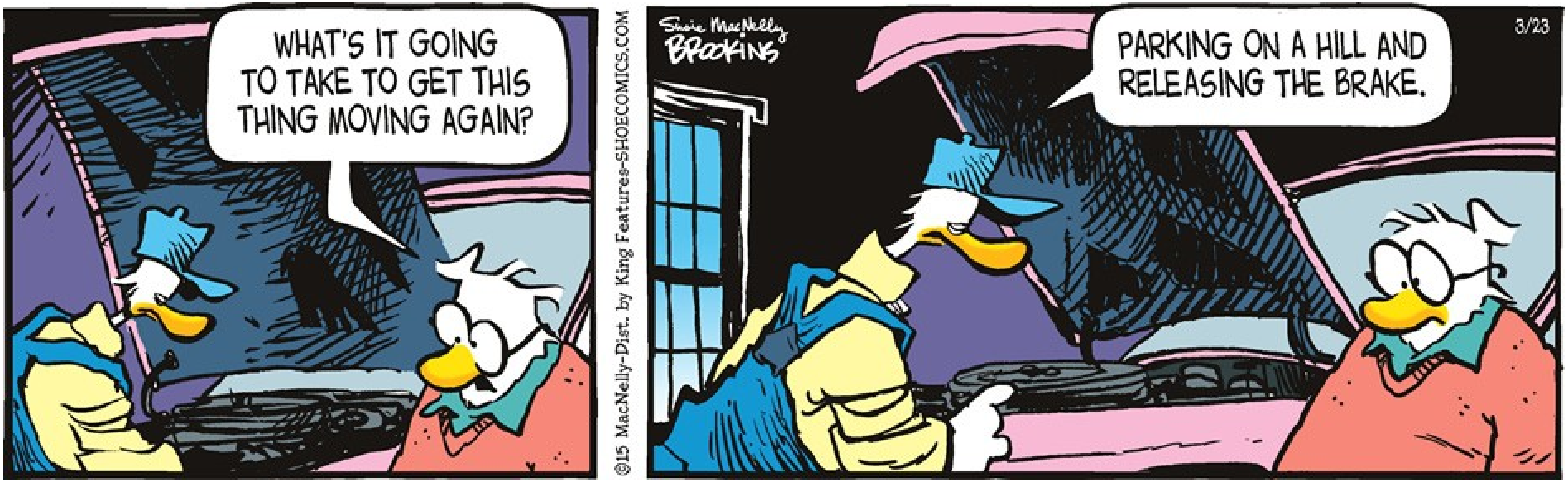
- **From knowledge about the size of dogs: a dachshund is unlikely.**
- **But if the visitor was in the habit of bending over to pet a dog, it might even be a chihuahua.**

Ambiguity in syntax: ***The chicken is ready to eat*.**

- **From knowledge about typical food: the chicken was cooked.**
- **If the word *chicken* were replaced with *dog*, one might assume the dog was begging for food.**
- **But people in different cultures may make different assumptions.**

There is no limit to the number of options.

Understanding Language



Syntax is easy: Parse the question and the answer.

Semantics is harder: Use context (background knowledge) to

- **Recognize the situation type and the roles of the two agents,**
- **Relate the word 'thing' to the picture and to the concept Car,**
- **Relate the verbs 'take' and 'move' to the situation,**
- **Apply the laws of physics to understand the answer.**

Pragmatics is the hardest: Explain the irony and the humor.

*** Source of cartoon: search for 'moving' at http://www.shoecomics.com/**

The Ultimate Understanding Engine

Sentences uttered by a child named Laura before the age of 3. *

Here's a seat. It must be mine if it's a little one.

I went to the aquarium and saw the fish.

I want this doll because she's big.

When I was a little girl, I could go "geek geek" like that, but now I can go "This is a chair."

Laura used a larger subset of logic than the Semantic Web.

No computer system today has her ability to learn, speak, and understand language.

*** John Limber, The genesis of complex sentences. In T. Moore (Ed.), *Cognitive development and the acquisition of language*. New York: Academic Press, 1973.**
http://pubpages.unh.edu/~jel/JLimber/Genesis_complex_sentences.pdf

Child Reasoning

A mother talking with her son, about the same age as Laura: *

Mother: ***Which of your animal friends will come to school today?***

Son: ***Big Bunny, because Bear and Platypus are eating.***

The mother looks in his room, where the stuffed bear and the platypus are sitting in a chair and "eating".

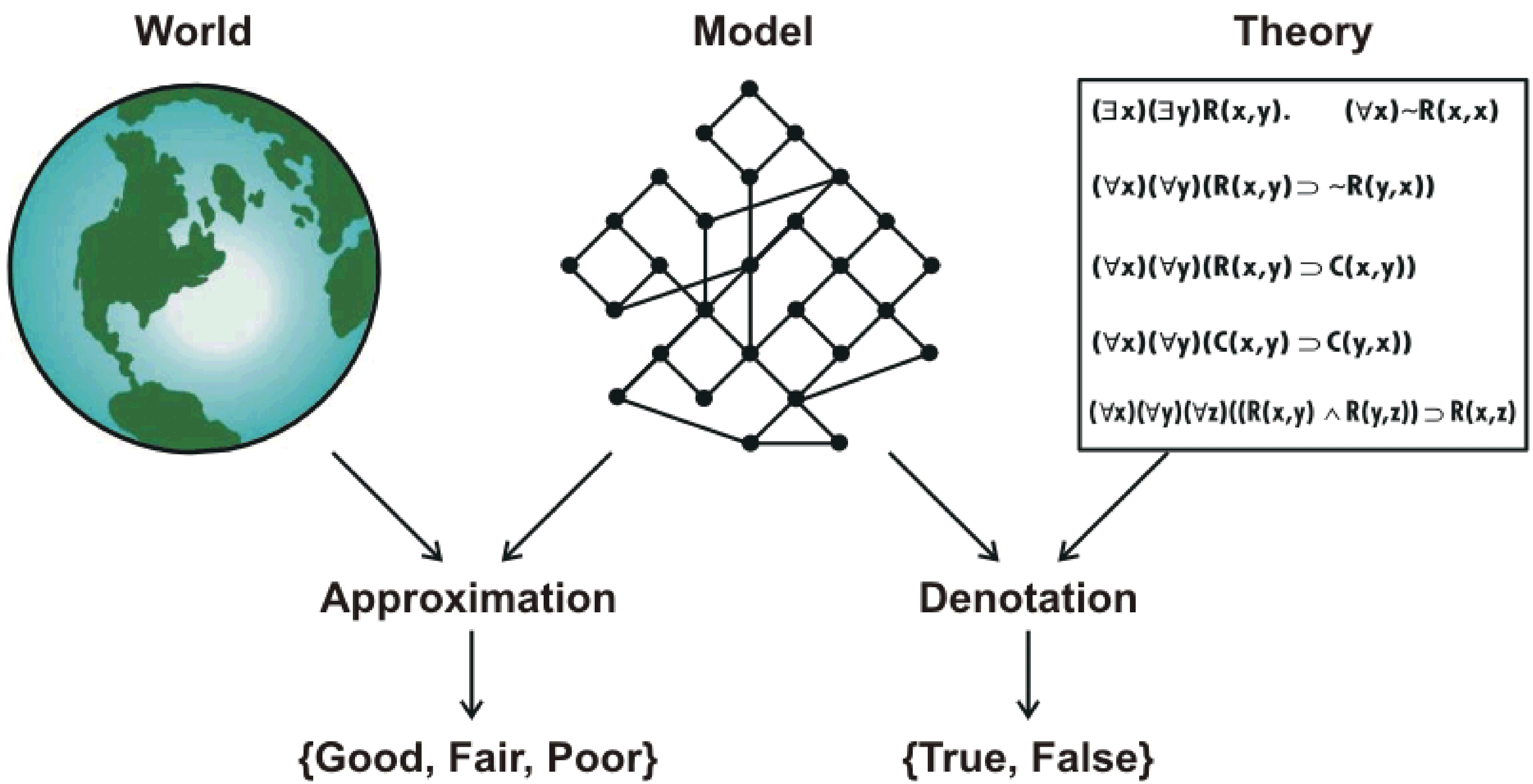
The child relates the sentences to the situation:

- **The bear and the platypus are eating.**
- **Eating and going to school cannot be done at the same time.**
- **Big Bunny isn't doing anything else.**
- **Therefore, Big Bunny is available.**

This reasoning is more "logical" than anything that Siri says.

*** Reported by the father, the psychologist Gary Marcus, in an interview with Will Knight (2015)**
http://www.technologyreview.com/featuredstory/544606/can-this-man-make-ai-more-human/#comments

Model-Theoretic Semantics



In the middle is a Tarski-style model that relates a theory to the world.

Logicians: The model is a subset of the world.

Engineers: ***"All models are wrong, but some are useful."***

The engineering view is more realistic.

Mental Maps, Images, and Models

Quotation by the neuroscientist Antonio Damasio (2010):

> ***"The distinctive feature of brains such as the one we own is their uncanny ability to create maps... But when brains make maps, they are also creating images, the main currency of our minds. Ultimately consciousness allows us to experience maps as images, to manipulate those images, and to apply reasoning to them."***

The maps and images form mental models of the real world or of the imaginary worlds in our hopes, fears, plans, and desires.

Words and phrases of language can be generated from them.

They provide a "model theoretic" semantics for language that uses perception and action for testing models against reality.

Like Tarski's models, they define the criteria for truth, but they are flexible, dynamic, and situated in the daily drama of life.

2. Situation Semantics

Meaning depends on the context of a sentence within the discourse and the situation of the speaker and listener.

But what is a situation?

- **A situation is an actual, hypothetical, or fictional region.**
- **For some reason, that region is significant for the participants.**
- **Language or logic may be used to describe a situation.**
- **Indexicals (pronouns and pointing words like *this* or *that*) relate the sentences to each other and to the situation.**

Problems of mapping language to logic:

- **How do we determine what situation(s) are significant for understanding a discourse or a document?**
- **How do we relate the indexicals to entities in the situations?**
- **How are situations related to other background knowledge?**

An Actual Conversation

A transcript, with background knowledge in italics: *

HUSBAND: Dana succeeded in putting a penny in a parking meter today without being picked up.

> ***This afternoon as I was bringing Dana, our four-year-old son, home from the nursery school, he succeeded in reaching high enough to put a penny in a parking meter when we parked in a meter zone, whereas before he has always had to be picked up to reach that high.***

WIFE: Did you take him to the record store?

> ***Since he put a penny in a meter that means that you stopped while he was with you. I know that you stopped at the record store either on the way to get him or on the way back. Was it on the way back, so that he was with you or did you stop there on the way to get him and somewhere else on the way back?***

HUSBAND: No, to the shoe repair shop.

> ***No, I stopped at the record store on the way to get him and stopped at the shoe repair shop on the way home when he was with me.***

*** Page 9 of https://web.stanford.edu/~kdevlin/Papers/Context_in_Reasoning.pdf**

The Context of a Conversation

The continuation of the previous conversation:

WIFE: What for?

> ***I know of one reason why you might have stopped at the shoe repair shop. Why did you in fact?***

HUSBAND: I got some new shoe laces for my shoes.

> ***As you will remember I broke a shoe lace on one of my brown Oxfords the other day so I stopped to get some new laces.***

WIFE: Your loafers need new heels badly.

> ***Something else you could have gotten that I was thinking of. You could have taken in your black loafers which need heels badly. You'd better get them taken care of pretty soon.***

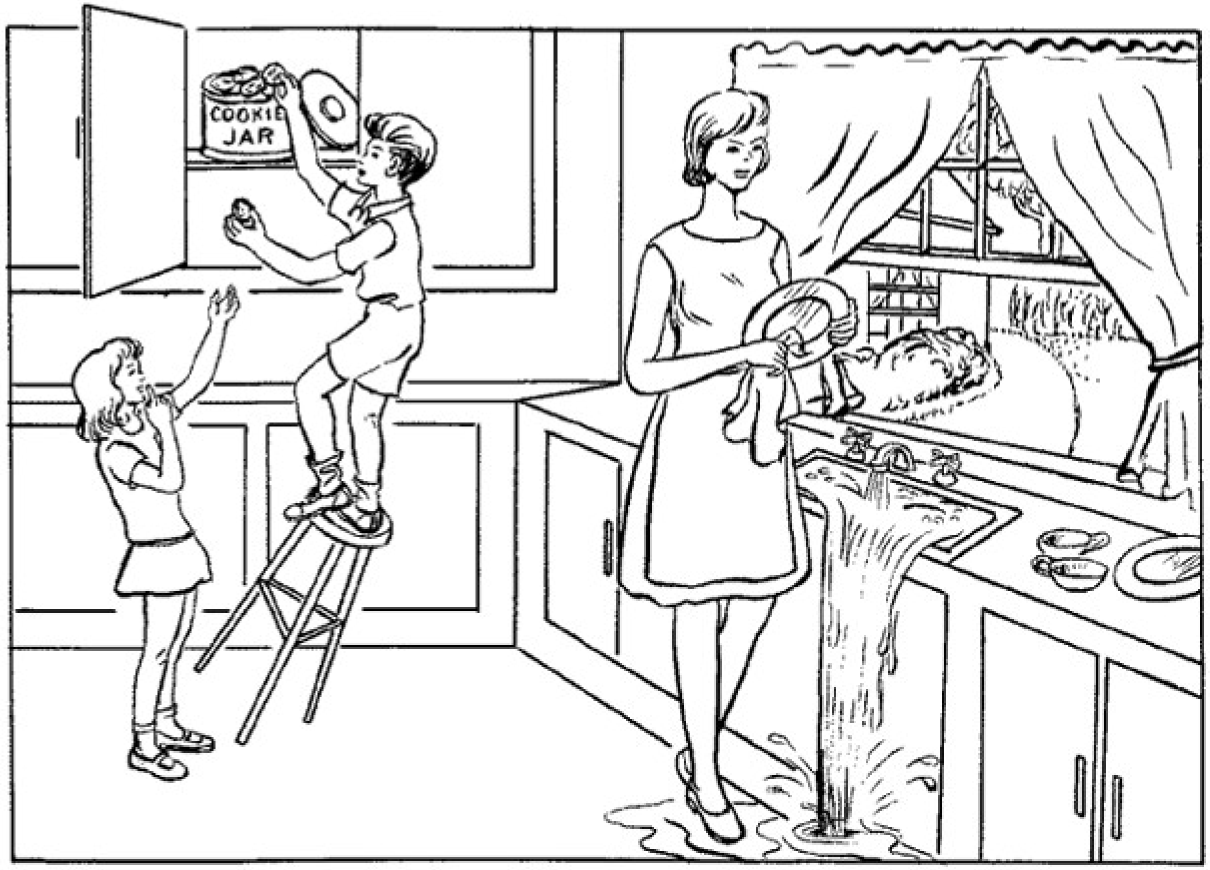
Observation by Keith Devlin: ***"The task*** **[*****of specifying all the relevant context*****]** ***was endless. At every stage, what has been specified is dependent on further contextual factors."***

The Boundaries of a Situation

Definition: A situation is a real or imagined region of space-time that bounds the range of perception, action, interaction, and communication of one or more agents:

- **The boundary of a situation is determined by the range of perception, action, and communication by the agents in it.**
- **A situation without agents is possible, but meaningless.**
- **Microscopes, telescopes, and TV use enhanced methods of perception and action to change the boundary of a situation.**
- **Psychologists and sociologists study human situations.**
- **Linguists and logicians formulate theoretical models of agents interacting in and talking about situations.**
- **Computer scientists develop methods for simulating and reasoning about the models.**

Example of a Situation



This is a test picture used to diagnose patients with aphasia.

A patient's description of the situation can show the effects of lesions caused by wound, stroke, tumor, or infection.

The "cookie theft" picture was adapted from Goodglass & Kaplan (1972).

Meaningful Aspects of the Situation

Space-time region of the "cookie theft" picture:

- Afternoon in the kitchen of a private home.

Agents:

- Girl, boy, woman.

Goals of the agents:

- Girl, boy: get cookies.
- Woman: wash dishes; maintain discipline.

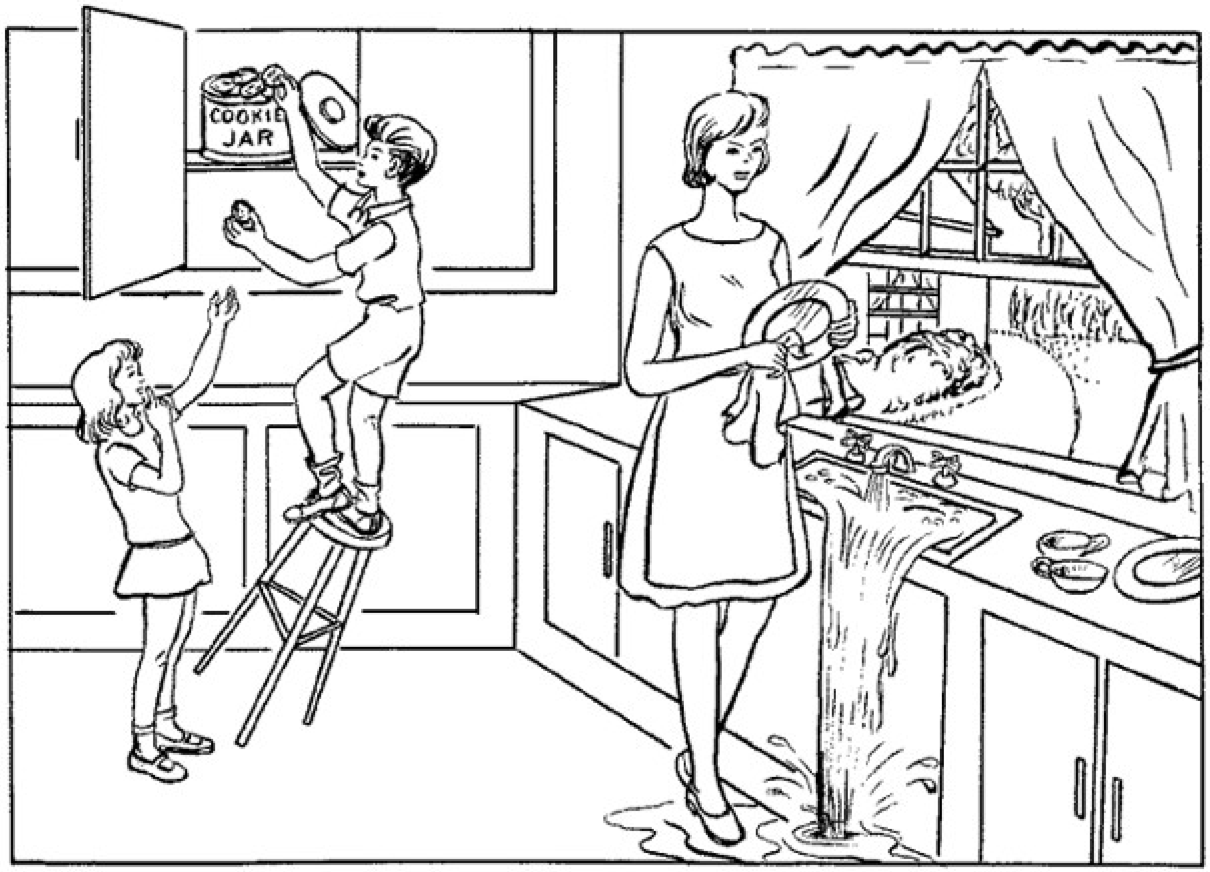
Actions:

- Wiping, spilling, reaching, holding, grasping, tipping, falling.

Question:

- How can we represent this situation in logic?

A Description in Controlled English



{Situation: ***A woman, a girl, and a boy are in a kitchen of a house. The woman wipes a plate with a cloth. Water spills on the floor of the kitchen. The girl reaches for a cookie. The boy holds a cookie in his left hand. The boy grasps a cookie with his right hand. The boy stands on a stool. The stool tips over. The boy falls down.*****}**

Situation Theory

Based on a book by Barwise and Perry (1983) and developed mostly at Stanford (CSLI) during the 1980s and '90s.

In situation theory, the unit of information is called an *infon* σ, which is entailed by some *situation s*: $s \models \sigma$

The meaning of a language expression φ is a relation between a *discourse situation d*, a *speaker connection function c*, and a *described situation e*: $d, c \| \varphi \| e$

Those relations may be expressed in some versions of logic:

- **A relation with all its arguments would represent an infon.**
- **A compound infon would be a Boolean combination of relations.**
- **But the logic would also require metalanguage or logic about logic.**

This kind of logic could represent the cookie-theft picture.

But the conversation about Dana is much more complex.

3. Representing Contexts in Logic

A complete statement of all contextual information is difficult, even for humans. (For example, see slides 10 and 11.)

But any contextual information that humans discover and state explicitly can be translated to logic.

Two operators are necessary and sufficient:

1. **A relation that says proposition p is true in context c.**
2. **A metalevel operator that encapsulates a block of statements.**

For #1, John McCarthy (1993) proposed the relation ist(c,p).

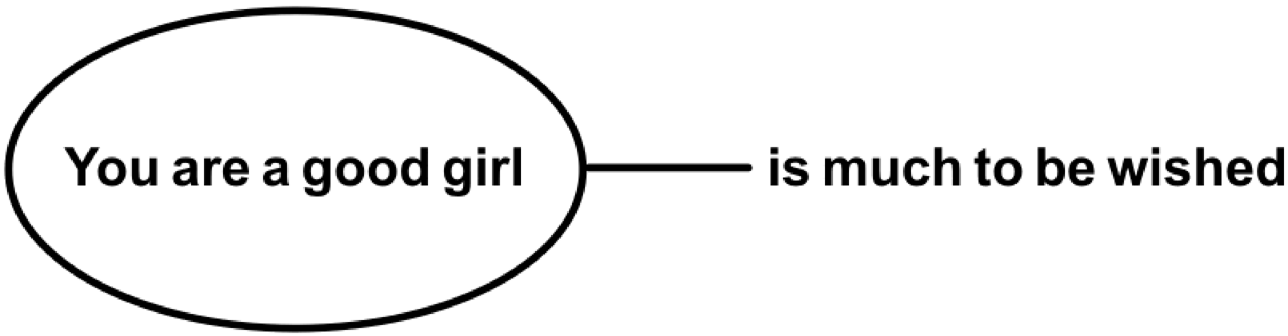
For #2, the IKL logic has an operator named *that*.

Any logic that supports metalanguage can be used to define an operator that corresponds to *that*.

With the ability to use metalanguae, the option of letting quantified variables range over propositions can support *ist*.

Peirce’s Metalanguage

In 1898, C. S. Peirce extended first-order logic with a graphical enclosure for encapsulating one or more statements in logic: *



The relation named 'You are a good girl' has zero arguments. It represents an existential graph that states a proposition *p*.

The relation named 'is much to be wished' is attached to a line that states the existence of something that is wished.

With these features, Peirce's graphs could represent contexts and the operators for representing and reasoning aout them.

* From Charles Sanders Peirce, *Reasoning and the Logic of Things*, The Cambridge Conferences Lectures of 1898, Harvard University Press, p. 151.

Tarski’s Metalanguage

In his paper “The concept of truth in formalized langugages,” Tarski (1933) used a metalanguage to specify truth in an object language.

For simplicity, he used the same syntax and semantics (first-order logic) for both the metalanguage and the object language

To avoid contradiction, Tarski kept the two levels distinct:

- The object level had a domain D, which included everything that the variables could refer to.
- But the metalanguage had a larger domain: it included D and all the syntactic features of the object language.
- Tarski also extended this principle to a hierarchy of metalanguages: the domain of each one included the domain of its object languge plus all its syntactic features.

Contexts in Conceptual Graphs

Conceptual graphs were designed as a combintion of Peirce's existential graphs with additional features from other logics.

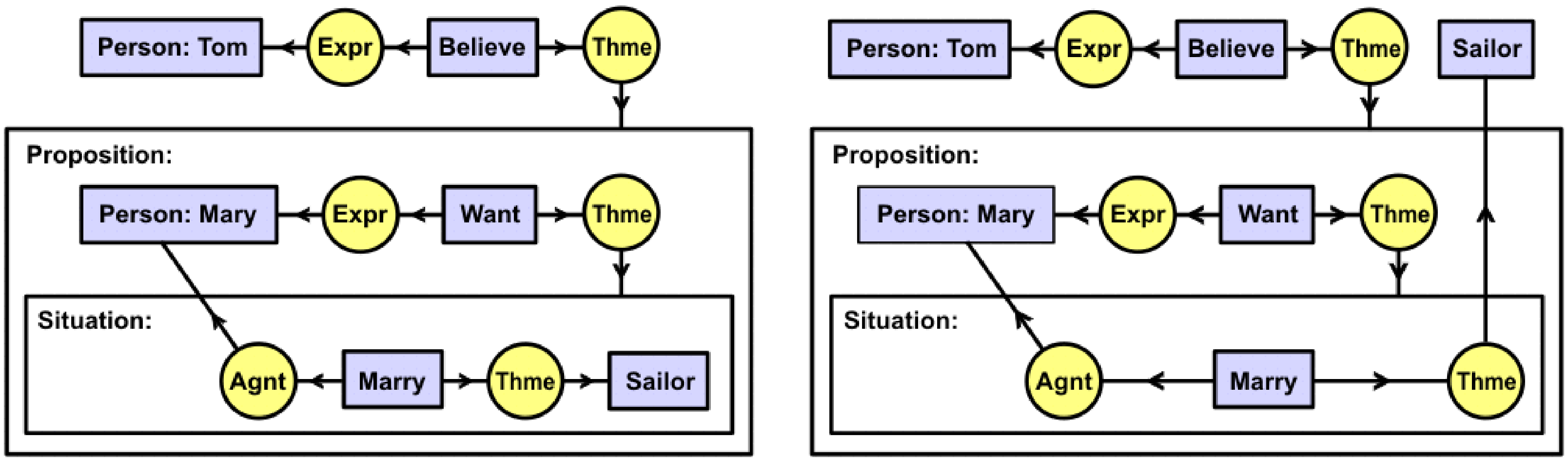
Metalanguage is represented by an enclosure, and it's semantics is based on a combination of Peirce, Tarski, and Hintikka.

When the ISO standard for Common Logic was developed, the Conceptual Graph Interchange Format (CGIF) adopted the formal semantics of Common Logic.

When IKL was developed, CGIF was extended to include the semantic extensions of IKL. *

* See http://jfsowa.com/ikl

Propositions and Situations



The two CGs above show two different interpretations of the English sentence *Tom believes that Mary wants to marry a sailor*:

- ***There exists a sailor, and Tom believes a proposition that Mary wants a situation in which she marries the sailor.***
- ***Tom believes a proposition that Mary wants a situation in which there exists a sailor whom she marries.***

A situation is a meaningful region of space-time described by the proposition stated by the nested CG.

For further discussion, see http://www.jfsowa.com/pubs/eg2cg.pdf

Representing Situation Theory

In situation theory, the unit of information is called an *infon* σ, which is entailed by some *situation s*: $s \models \sigma$

The meaning of a language expression φ is a relation between a *discourse situation d*, a *speaker connection function c*, and a *described situation e*: $d, c \| \varphi \| e$

All those relations can be expressed in Common Logic:

- **A single relation with all its arguments corresponds to an infon.**
- **A compound infon is a CL expression that combines the relations.**
- **The theory, notation, and terminology by Devlin (1991) can be directly mapped to any dialect of CL.**

The IKL extension to CL provides a rich formalism for talking about situations, agents, and the intentions of the agents.

Controlled NLs can serve as a notation for CL and IKL.

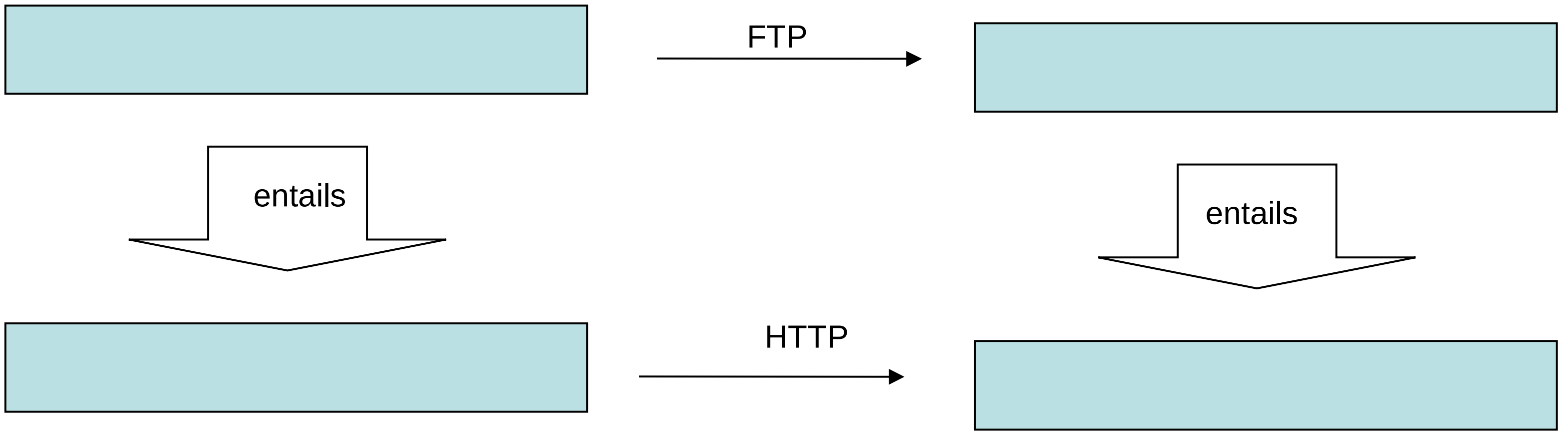
IKL

Common Logic on steroids

The following slides, written by Pat Hayes, are a subset of http://jfsowa.com/ikl/hayes06.ppt

IKL is a network logic

- IKL meanings do not change when IKL text is stored, transmitted, combined with other IKL text, or re-used
- IKL names refer and identify uniformly across a network
- IKL text from multiple sources can be combined freely without requiring negotiation.
- IKL entailment commutes with transfer protocols



IKL is a transparent logic

- Every occurrence of an IKL name has the same meaning.
- Equality substitution applies everywhere in IKL

  IKL is not indexical or referentially opaque (contextual, modal, tensed, belief, hybrid)

  Multiple referents for IKL names are handled by explicit functions on *quoted* names

  Descriptions which are relative to times, places, contexts, states of belief, points of view, etc., are made in IKL by relating *propositions* to the time, place, context, etc., explicitly.

  IKL both supports and requires *ontologies of context*.

IKL features from CL

- Names can be any Unicode character sequence
  John_Doe “John Doe”   08-21-1944   "John\(Doe\)"
  ÇZÜKJÖV "\00C7Z\00DCKJ\00D6V"

- IKL can refer to and quantify over classes, properties, relations, functions, integers, character strings and ontologies.

- IKL texts can be named and imported into other texts; modules provide for a local universe of discourse

- Comments can be in any format and attached anywhere.

propositions

- can refer to, and quantify, over *propositions* expressed by sentences.

  (exists (x)(and (Person x)(taller x Bill)))

  (that (exists (x)(and (Person x)(taller x Bill))))

  Proposition name

- propositions are real things that can be related to others

  (Believes Mary (that (forall (x)(if (Person x)(smarter Bill x)))))

  (LessLikelyThan (that (forall (x)(if (Person x)(smarter Bill x))))
  (that ((AND Cheese Green)(materialOf Moon))))

  and can be quantified, be the value of functions, etc.

  (Believes Fred (Not (that (exists (p)(Believes Mary p)))))

- names *inside* proposition names work as usual, so you can quantify into them and reason about them

  (forall ((x Person))(Believes Mary (that (smarter Bill x))))

propositions

- Propositions are identified with zero-ary relations, and handled similarly.

- Applying a proposition name to no arguments

  ((that (Married Bill Sue)))

  gives an atomic sentence which says the same thing as the sentence expressing the proposition.

  ~~((that~~ (exists (x)(and (Person x)(taller x Bill))~~)~~ ~~)~~

  (exists (x)(and (Person x)(taller x Bill))

- The outer calling brackets can be read as 'it is true …'
  - *It is true that a person exists who is taller than Bill*

- Or, one could say that the calling brackets *cancel that*.

propositions are very handy

Talk about beliefs (for example)

(forall (x)(if (Believes Mary x)(Believes Joe x)))

(forall (x)(if (Believes Mary x)(not (x))))

Assert properties of propositions

**(forall (p (x agent))(if (less (secLevel x)(secLevel x))
(prohibitedEvent (awareOf x p))))**

Define functions on propositions

(forall (x)(= (Not x)(that (not (x)))))

Give names to complex propositions

(= hypothesis17 (that (member Joe Al_Quaeda)))

but beware of inherent contradictions

?? (= p (that (not (p)))) ??

Describe relations between propositions and contexts

(ist context39 (that (member Joe Al_Quaeda)))

Define classes of propositions

**For more about the distinction between sentences and propositions,
see http://jfsowa.com/logic/proposit.pdf**

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identity of propositions

- When do two sentences express the same proposition?

- If two propositions are equal then their expressing sentences are equivalent:

  (if (= p q) (iff (p)(q)))

  … but maybe not the reverse.

- Identical propositions should be 'about the same things'

  A proposition expressed by a sentence is *about* the things referred to by the free names in the sentence.

identity of propositions

Logical equivalence of sentences is too inclusive
Syntactically same sentence is too fine-grained

- The special relation =P provides an intuitive notion of 'same proposition' for use in writing axioms [John Sowa]

```
(=P (that (and A B)) (that (and B  A)) )
(=P (that (or A  B C ... ))(that (not (and (not A)(not B)(not C)...))))
      (=P (that (and A (and B C)))(that (and (and (A B) C))))
(=P (that (if A B)(that (or (not A) B)) )
(=P (that (iff A B))(that (and (if A B)(if B A))))
      (=P (that (and A A) (that A))
(=P (that (forall (n) A)) (not (exists (n) (not A))) )
      IF  (= n m)  THEN  (=P (that A) (that A[n/m] ))
```

- =P is decidable between sentences in n.log-n time

- If (=P x y) then x and y are 'about the same things'.

IKL can represent content expressed in many other kinds of logic

1. Modal and hybrid logics

   knows, believes

   future, past; true when

   should be, is prohibited

2. Temporal logic

   holds

3. Context logic

   ist

Other logics and IKL

- IKL can represent content expressed in many other kinds of logic

  But…translating these into IKL often requires more than a simple syntactic transformation in order to fully capture the intended meaning.

  Some logics are designed with particular ontological presumptions in mind, which must be made explicit in IKL ontologies.

For example, a tensed language assumes an underlying time structure of points or intervals, and modal languages assume a structure of 'alternative worlds'.

Modal languages and IKL

- Classical semantics for modal languages due to Kripke, describes structure of *alternative possible worlds*. Different kinds of 'alternativeness' (transitive? reflexive?) give rise to different modal axioms.
- This translates into IKL (in fact, into GOFOL) using the same kind of techniques used for temporal logics, using explicit ontologies for possible worlds (e.g. situation calculus) *provided that names refer coherently*, so that they can be 'sliced'.
- If not, we have to be more subtle. Captured names with subscripts can be used to approach the general case.
- Modalities of obligation and permission can be expressed in IKL using ontologies of obligated and permitted *events* or *actions*.