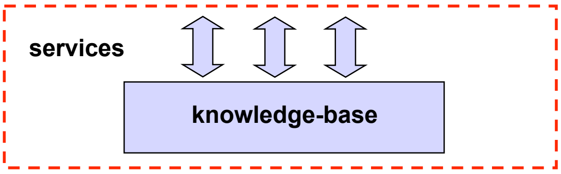
Representations and Processes in Knowledge-based Systems

Characteristics of ideal knowledge-based systems:

- Problems are specified by background and task knowledge using a declarative knowledge representation language
- Problems are solved using standard inference procedures

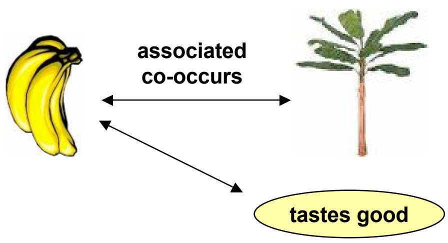
Knowledge representation formalisms must support representations and processes (inferences)!

A knowledge-base may be considered as a module providing standardized services.



Knowledge Representation and Management in Early Humans

By nature, knowledge in humans is organized as an associational network.



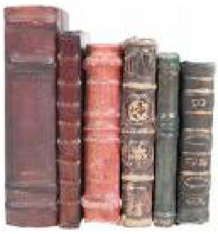
Associational networks are built by experience.

Knowledge is "tranferred" by guided experiences.

Language-based Knowledge Representation and Management

Natural language is the best-developed communication medium between humans.

Written and printed natural language texts are the traditional means for human knowledge representation and management.



Early work in Computer Science and Artificial Intelligence on knowledge representation and management had the primary goal to deal with knowledge in terms of natural language texts.

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"Semantic Memory" of Quilian (1966)

Quilian is considered the inventor of Semantic Networks: Representation of word meanings composed of nodes and associative links

nodes = word concepts
links = pointers to related word concepts
planes = delineations for word definitions

Small set of link types:

- subclass
- modification
- disjunction / conjunction
- subject / object

Inferences by "spreading activation intersection search"

=> intent to infer knowledge not explicitly represented in memory

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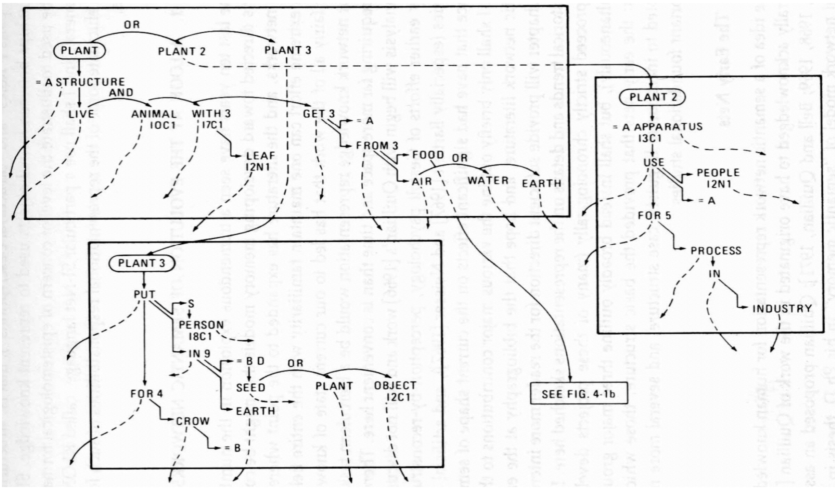
Example of Quilians "Semantic Memory"

1. *Living structure which is not an animal,frequently with leaves, getting its food from air, water, earth*
2. *Apparatus used for any process in industry*
3. *Put (seed, plant etc.) in earth for growth*

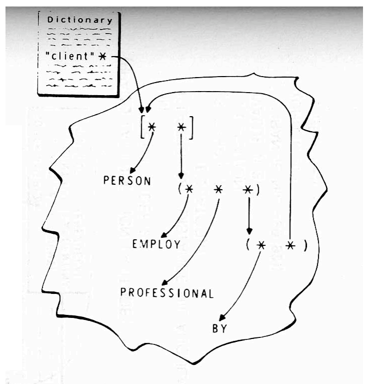


Quilian´s Semantic Network with a Single Link Type (1969)

In the "Teachable Language Comprehender" (TLC) Quilian cleaned up link types and allowed only a single pointer type.

"Units" represented concepts by
- **superset**
- **refining properties**

"Properties" were defined by
- **a name**
- **a value**
- **possibly subproperties**



Example: ***A client is a person which is employed by a professional***

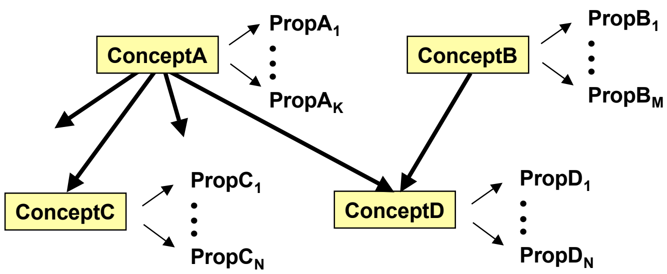
The TLC failed due to erroneous spreading activation inferences caused by the unclear semantics of pointers.

Inheritance Hierarchy by Collins and Quilian (1970)

An inheritance hierarchy is a Directed Acyclic Graph (DAG) with concept nodes and inheritance links.

A child node

- inherits all properties of its parent nodes,
- may refine inherited properties,
- may add new properties.



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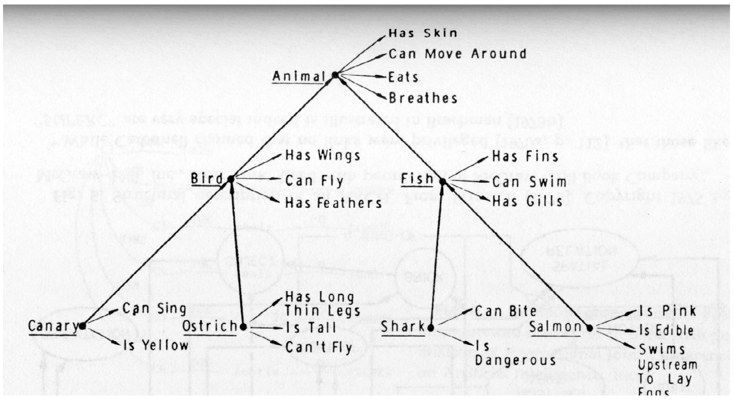
Cognitive Plausability Test for Inheritance Hierarchies

Comparison of human reaction times for confirmation or refutation of assertions such as "A canary has skin" or "A canary can sing":

=> inconclusive results

But invention of notion of "semantic distance"!



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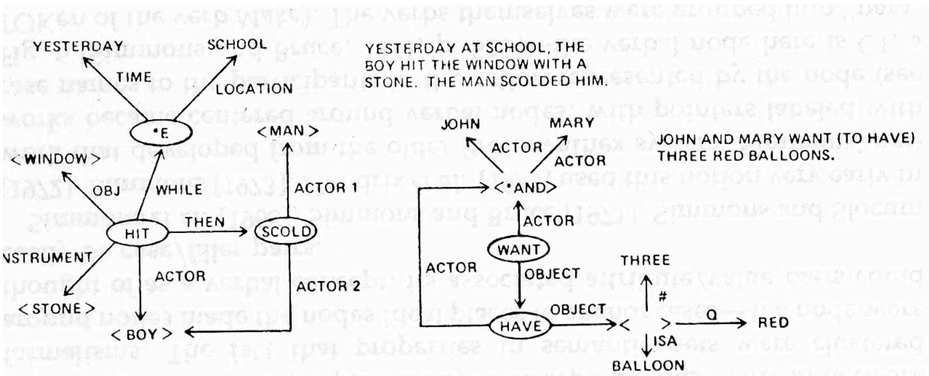
Rumelhart´s Verb-centered Semantic Networks (1972)



Verbs are anchor points for "deep cases", e.g. objective, instrumental.

Unclear semantics, also due to the use of ISA for both subconcepts and instances (!)

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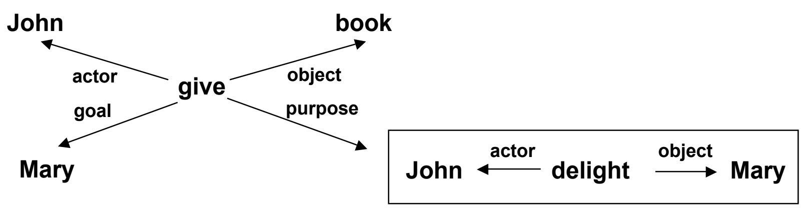
Fillmore´s Deep Case Relations (1968)

Verbs (in particular action verbs) are accompanied by linguistic expressions which specify "deep cases" semantically related to the verb.

Example: ***John gave Mary a book to delight her.***

actor goal object purpose



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Examples for Deep Cases

"On a sunny day, the farmer and his wife wheeled the refrigerator with a cart from their house on a bumpy road along their meadows to the garbage dump in the vicinity to get more space in their kitchen."

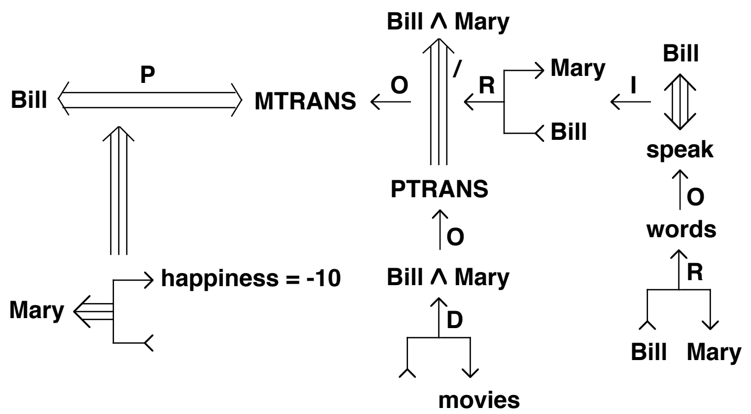
"sunny day"	time	time of action
"farmer"	agent	causes an action
"his wife"	coagent	supports the action, subordinate to the actor
"refrigerator"	object	is directly affected by the action
"cart"	instrument	tool or means for achieving the action
"house"	origin	position of object before the action
"road"	location	place of the action
"meadows"	path	position of object between origin and destination
"garbage dump"	destination	position of object after the action
"get more space"	purpose	indirect goal of action

Can you find more deep cases? Is their a fixed set of deep cases?

Schank´s Conceptual Dependency Theory (1973)

Using a limited number of primitive semantic relations, MARGIE could obtain a deep conceptual structure from NL sentences and rephrase them.

"Bill told Mary, he would not go to the movies with her. Her feelings were hurt."



Schank´s Primitive Relations

PP	⇔	ACT	an agent acts
PP	⇔	PA	an object has an attribute
ACT	← O	PP	object of an action
ACT	← R (→ PP, ← PP)	PP / PP	giver and receiver of an object in an action
ACT	← D (→ PP, ← PP)	PP / PP	direction of an object in an action
ACT	← 1 ⇕		conceptualized instrument for an action
	X ⇑ Y		conzeptualization X causes conzeptualization Z (with C: could cause)
PP	⇐ (→ PA2, ← PA1)	PA2 / PA1	state change of an object
PP1	←	PP2	PP2 is part of or owner of PP1

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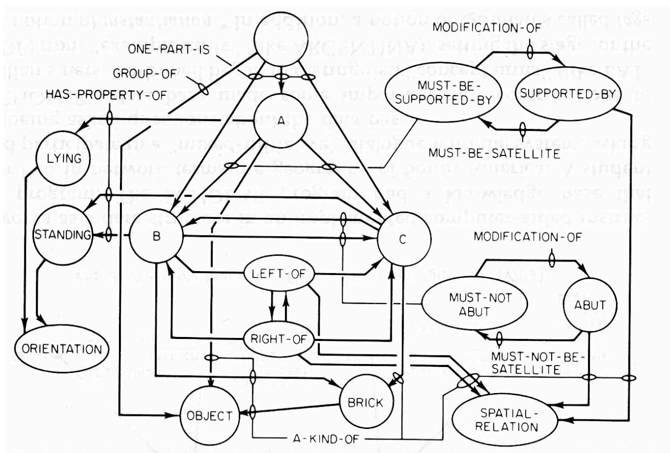
Winstons Structural Descriptions (1975)

Structural description of an ARCH, learnt from examples.

Winston was the first to relate relations to each other, e.g.
LEFT-OF = OPPOSITE RIGHT-OF



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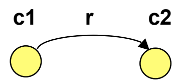
General Properties of Semantic Networks?

Graphical representation of binary relations:
labelled nodes = concepts
directed labelled edges = binary relations



But where are the semantics?

Are there any nodes or node types and links or link types which are valid in general, independent of a particular domain?

Is there any structuring rule which is valid in general, independent of a particular domain?

Are there generally valid inference procedures to derive knowledge which is not explicitely stated?

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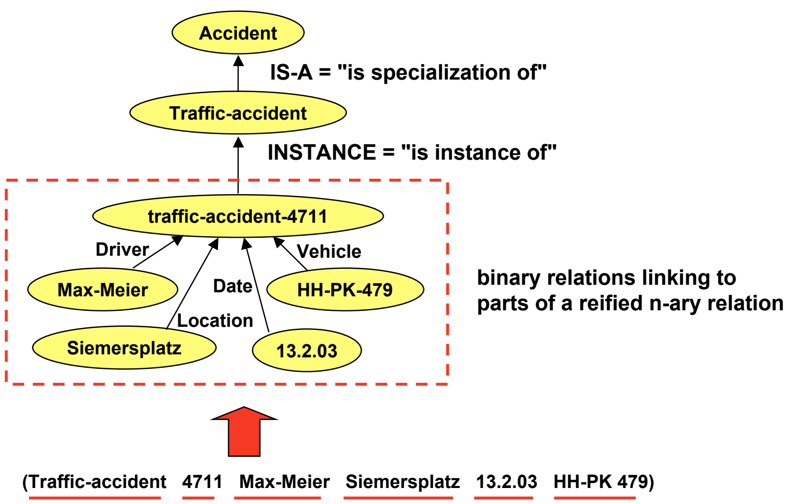
Basic Relations in Semantic Networks



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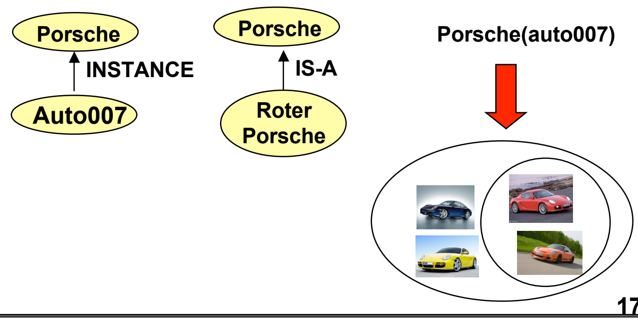
Formal Semantics of is-a and instance

(see "Grundlagen der Wissensverarbeitung")

An interpretation is a triple I = <D, ϕ, π> where

- D is a domain of individuals,
- ϕ is a mapping that assigns an element of D to each constant occurring in the representation
- π is a mapping that assigns to each n-ary predicate symbol a function from D^n into {true, false}.

Knowledge representation:



Real world domain:

What is a Concept?

- A concept is a unary predicate P( ).
- Its semantic is defined by an interpretation I = <D, ϕ, π>.
- The interpretation specifies the extension of the concept in terms of domain objects for which the unary domain predicate π(P) is true.

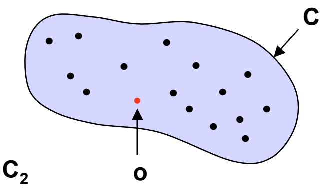
Loosely, a concept represents a set of objects.

Concepts and Individuals

Nodes of a Semantic Network describe concepts and individuals.

A concept denotes a set of objects.

An individual denotes a single object.



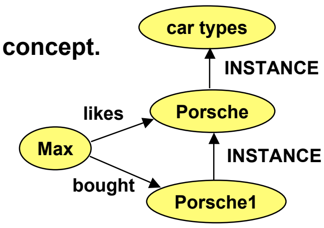
C_1 IS-A C_2 **specifies that C_1 is a subset of C_2**

o INSTANCE C **specifies that o is a member of C**

A node may represent both, an individual and a concept.
Example:

Max likes a Porsche.

Max bought a Porsche at the car dealer.



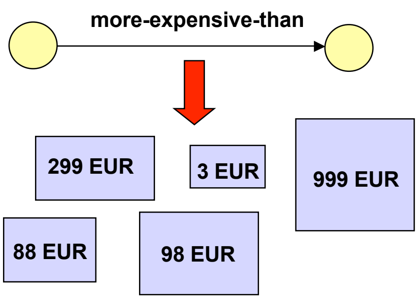
Formal Semantics of Links

- **A link is a binary predicate P(,)**
- **Its semantic is defined by an interpretation I = <D, ϕ, π>.**
- **The interpretation specifies the extension of a link in terms of pairs of domain objects for which the binary domain predicate π(P) is true.**

Loosely, a link represents a set of pairs of objects.

Knowledge representation:

Real world domain:



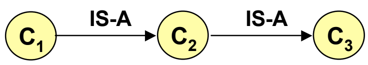
What Inferences are Possible?

Note that in general a computer has no access to the domain.

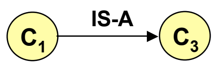
⇒ The computer cannot decide, if a representation is true in a particular interpretation.

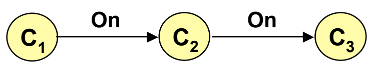
⇒ The computer can only infer knowledge which is true for all interpretations.

Examples:

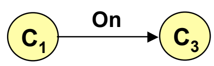


valid inference:





this inference is not always valid:



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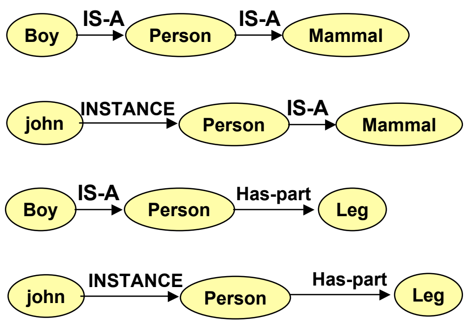
Inferences in Semantic Networks

Examples



Rules

C_1 IS-A C_2
C_2 IS-A C_3 => C_1 IS-A C_3

c INSTANCE C_1
C_1 IS-A C_2 => c INSTANCE C_2

C_2 Rel C_3
C_1 IS-A C_2 => C_1 Rel C_3

C_2 Rel C_3
c INSTANCE C_2 => c Rel C_3

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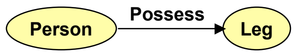
Inferences Based on Links

What is the meaning of C_1 Rel C_2 ?



1. All persons possess at least one leg
2. All persons possess exactly one leg
3. All persons possess zero to infinity legs
4. All objects which a person possesses are legs
5. Possessing means that a person has a least one leg
6. Possessing means that a person has exactly one leg
7. Possessing means that a person has zero to infinity legs
8. There is at least one person which possesses at least one leg
9. There is at least one person which possesses exactly one leg
10. There is at least one person which possesses zero to infinity legs
11. Every leg is possessed by at least one person
12. Every leg is possessed by exactly one person
13. Every leg is possessed by zero to infinity persons

Are there more possible meanings?

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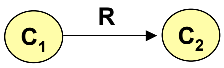
Clarification of Link Semantics (1)

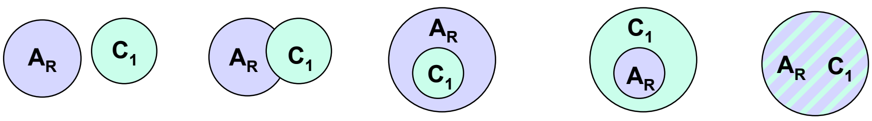
Two linked concepts involve five sets:



1) domain concept C_1
2) range concept C_2
3) pairs of objects constituting R
3) domain A_R of R
4) range B_R of R

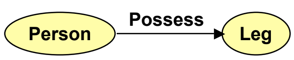
$R \subseteq A_R \times B_R$

A_R and C_1 (same for B_R and C_2) may be related as sets in five ways:



disjoint | overlap | A_R contains C_1 | C_1 contains A_R | equal

Check set relationships for:



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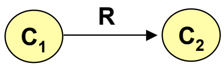
Clarification of Link Semantics (2)

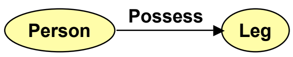
Intuitive interpretation of 

with $R \subseteq A_R \times B_R$

is most commonly: $\forall a \in (C_1 \cap A_R) \Rightarrow \exists b \in (C_2 \cap B_R) \wedge (ab) \in R$

Note the intuitive (but not compelling) cardinality restriction on the range of the relation!

Example:



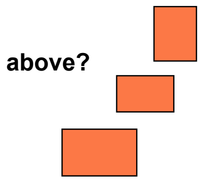
C_1	Person
C_2	Leg
A_R	Possessor
B_R	Possessee (possessed object)

"For all persons which are possessors there exists a leg among the possessees such that the person possesses the leg"

Special Semantics for Special Relations

Special relations may support special inferences.

Examples:



Above(a, b) $\wedge$ Above(b, c) => Above(a, c)

Left(a, b) => Right(b, a)

Has-part(a, b) $\wedge$ Has-Part(b, c) => Has-Part(a, c)

The rules for inferences may change from domain to domain, hence they must be explicitely stated.

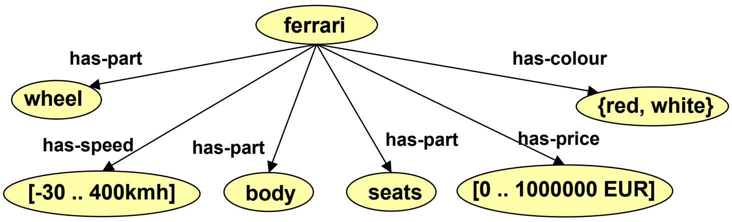
$\Rightarrow$ "axiomatizing a domain"

Spatial Reasoning, Temporal reasoning, Mereology are disciplines dealing with axiomatizations of spatial, temporal and part-of relationships, respectively.

Explicit and Symbolic Representations

Concepts may be described by a symbol (the name of a concept) or by an explicit value descriptor.

Example:



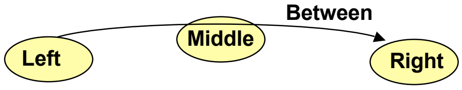
Typically, symbols are used for complex concepts composed of several constituent concepts, and explicit value descriptors for simple concepts specifying a range of numerical values or a set of symbolic values.

Compare with simple and complex data types!

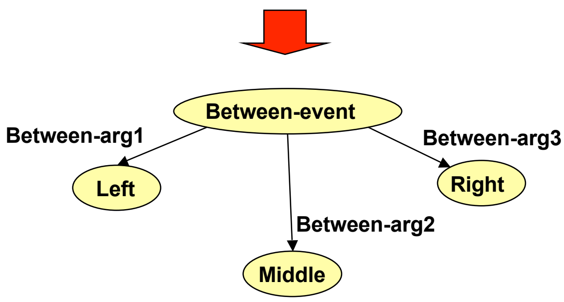
N-ary Relations in Semantic Networks

Semantic Networks allow the representation of binary relations only.
But any N-ary relation can be represented by multiple binary relations.

Example:

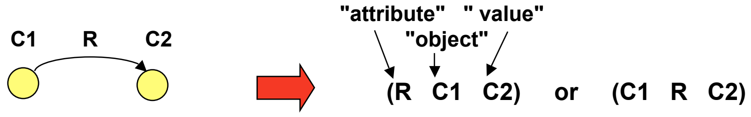


Between(Left, Middle, Right)



Attribute-Object-Value Triplets

In knowledge representation languages and programming languages, a Semantic Network can be represented by a set of triplets:



The accident example:

(is-a traffic-accident accident)
(instance traffic-accident-4711 traffic-accident)
(driver traffic-accident-4711 Max-Meier)
(location traffic-accident-4711 Siemersplatz)
(date traffic-accident-4711 13.2.03)
(vehicle traffic-accident-4711 HH-PK-479)

Note:

- notions of "attribute", "object" and "value" do not always seem fitting
- notation is not object centered

Frames

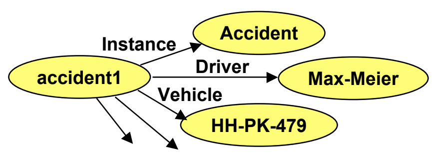
Frames have been proposed as knowledge representation structures for representing interrelated knowledge in larger units, in particular object-centered knowledge.

Marvin Minsky: "A Framework for Representing Knowledge", 1975
(often cited for promoting frames, but did not create any clarity about frame semantics)

Simple frame structure for the individual "accident1":

ID:	accident1
Instance:	accident
Driver:	Max-Meier
Vehicle:	HH-PK-479
Location:	Siemersplatz
Date:	13.2.03
Damage:	5000-EUR
Police Report:	HH-2003-AX4711
Witness:	Karl-Kruse

- Slots represent binary relations:



- Slot fillers may be primitives or frames
- Inheritance and other inference services may be provided

Facets and Procedural Attachment

- **Slot values are typed by "meta-types" and organized into facets.**
  - actual value
  - default (preset) value
  - value obtainable by procedure call
  - value obtainable by user inquiry
- **Attached procedures provide knowledge services as "demons" (without explicit invocation).**
  - for value computation
  - for checks before value change
  - for activities after value changes

Treat frames as plane frames but get more for value for your money!

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Frame Representation Language FRL

- **Facet names specify different slot filler "metatypes":**

$DATA	**normal data**
$DEFAULT	**default values**
$IF-ADDED	**write-access triggers specified demon procedures**
$IF-NEEDED	**read-access triggers specified demon procedures**
$REQUIRE	**demon procedures check conditions which must be met by slot fillers**

- **Built-in inference services enriched by demon procedures**

Example:

ID:	**($DATA Person007)**
Is-a:	**($DATA Person)**
Name:	**($DATA Max-Meier)**
Age:	**($REQUIRE Agetest)**
	($DATA 27)
Nationality:	**($DEFAULT German)**
Hobbies:	**($DATA Eating, Sleeping, Singing)**
	($IF-ADDED Singing Notify-Uni-Choir)
Phone:	**($IF-NEEDED Directory-Retrieval-Service)**
Address:	**($DATA Address4711)**

Values are retrieved

1. **from $DATA facet**
2. **by inheritance from parent $DATA facets**
3. **from $DEFAULT facet**
4. **by inheritance from parent $DEFAULT facets**
5. **by $IF-NEEDED demon procedures**

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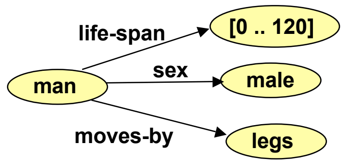
Semantics of Frames

Frames as concept descriptions

man		
	moves-by:	legs
	life-span:	[0 .. 120]
	sex:	male

semantics as

(man moves-by legs)
(man life-span [0 .. 120])
(man sex male)



Do we mean:

"Any object moving by legs, life-span 0 to 120 and sex male is a man"

or

"If an object is a man, it moves by legs, has life-span 0 to 120 and sex male"

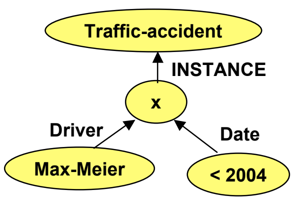
The semantics of frames is not well-defined!

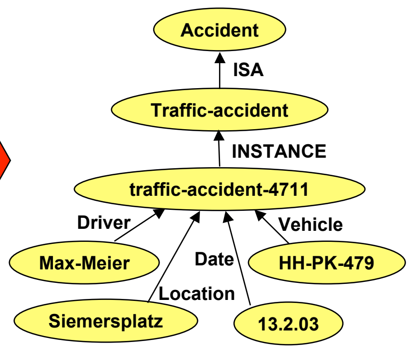
Matching Relational Structures

Semantic Networks applications often involve matching one network against another.

Example:

Has Max Meier been the driver in any traffic accident before 2004?





What services are required? What are the matching rules?

Semantic Network Queries

A Semantic Network (SN) query is a description of desired query responses in terms of a SN using an extended concept language.

Typical concept language extensions:

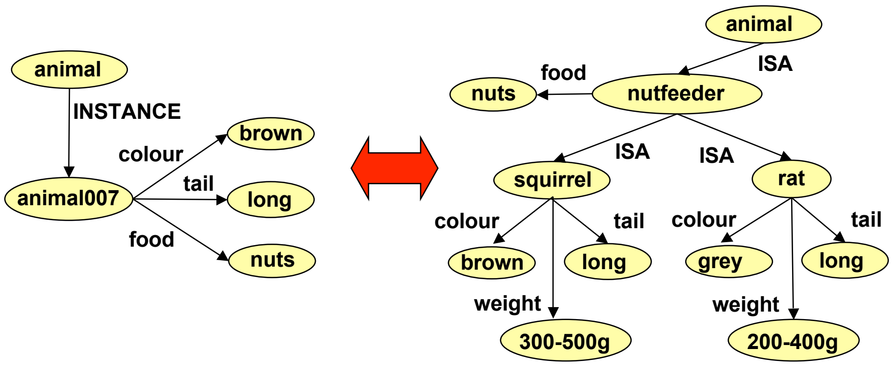
x	individual variable
X	concept variable
{a, b, c}	set of individuals
< 2004	predicate over a concrete domain individual

<u>Matching rules</u>:

A query Q matches a database D, if there is an injective mapping of all nodes and links in Q to nodes and links in D such that the corresponding nodes and links are compatible.

Design compatibility rules as an exercise!

Object Classification by Relational Matching



- INSTANCE and ISA inheritance must be exploited for matching
- Open-World-Assumption (OWA) must be applied to object description
- Class decriptions must be given in terms of sufficient conditions

Summary of Semantic Networks

- Intuitive graphical knowledge representation formalism with nodes representing concepts and individuals, and links representing relations
- Semantics of relations is well-defined for ISA and INSTANCE, but not clearly defined in general.
- Relations between relations cannot be expressed.
- The notion of an object and of object properties is not explicitely supported.
- Some services (basic information retrieval, basic classification) can be supported by pattern matching.
- Generally useful services require additional formalisms such as rules and rule-based inferences, e.g. for axiomatizing domains.

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