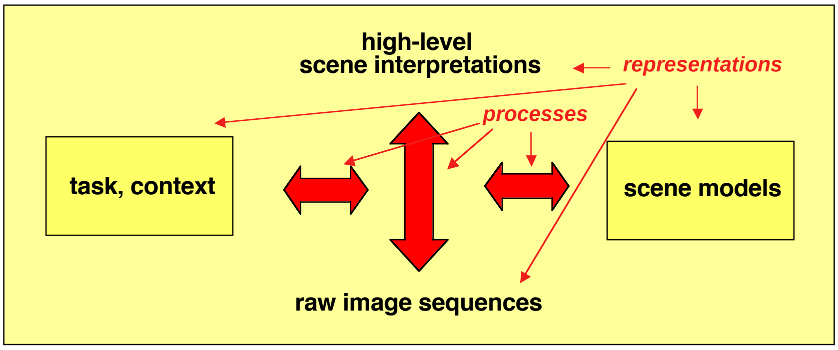
Representations and Processes in Knowledge-based Systems



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

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Review of Knowledge Representation Formalisms

- Semantic Networks
- Frames
- Constraints
- Probability distributions, Bayes Nets
- Rules
- Predicate Logics
- Description Logics
- Automata
- Grammars

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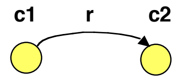
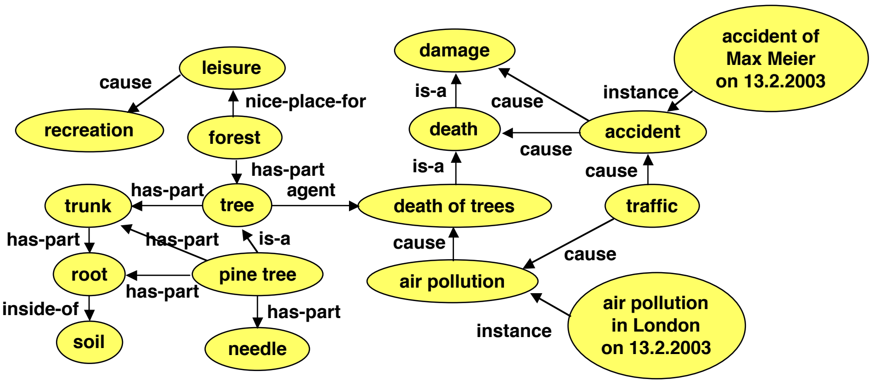
Semantic Networks

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



Semantic networks were originally developed to model associations between concepts in the human mind.



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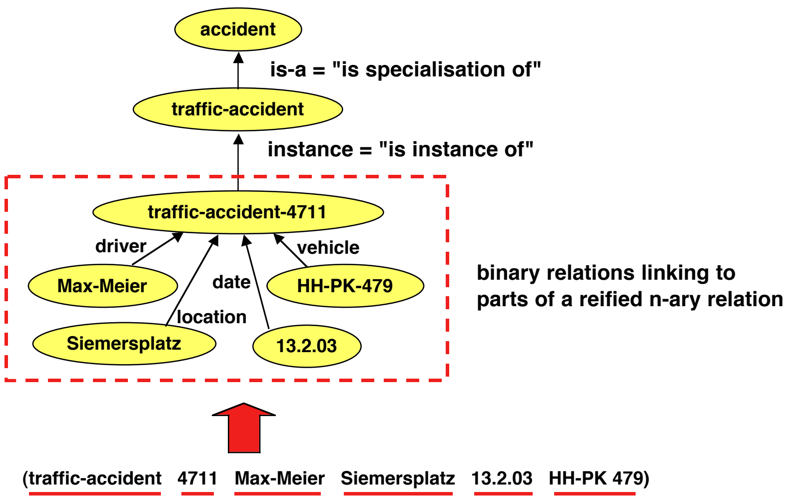
Basic Relations in Semantic Networks



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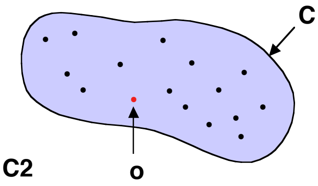
Concepts and Instances

Nodes of a semantic network describe concepts and individuals.

A concept denotes a set of objects.

An individual denotes a single object.



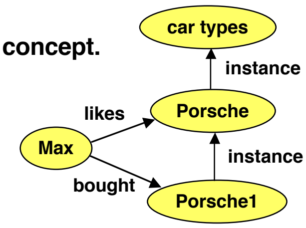
C1 is-a C2 **specifies that C1 is a subset of C2**

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

A node may represent both, an individual and a concept.
<u>Example</u>:

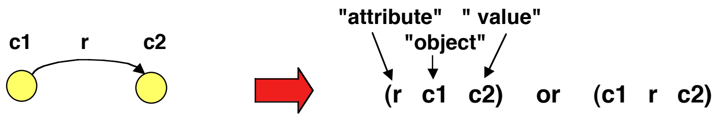
Max likes a Porsche.

Max bought a Porsche at the car dealer.



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)

<u>Note</u>:

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

Physical Object Descriptions

Scene interpretations are based on information about physical objects.
Hence concepts and relations about the "physical reality" are important.

Characteristics of physical object descriptions:

1) Individuals
- A description is valid for an absolute time point or period
- Nodes denote individual physical objects (or object parts)
- Objects have a spatial extent
- Objects often have a shape and appearance
- Objects are often described in terms of location and orientation
- Objects obey physical laws

2) Concepts
- Concepts define equivalent classes by abstracting from invidual properties
- Abstractions may be defined in terms of qualitative properties
- Abstractions may involve relations to other objects

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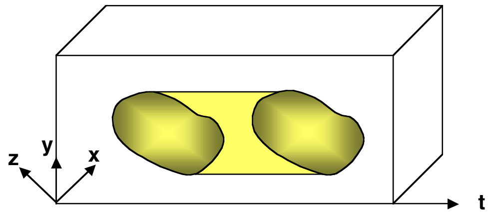
Objects in Space-Time

An epistemologically well-founded way of defining an individual physical object is in terms of a subspace of 4-dimensional space-time.



Example: The potatoe lying on the Max Meier´s table from 11:45 until 12:10 on August 8, 2003.

Individual physical objects which keep their identity over time constitute a common kind of abstractions.

Example: Max Meier is considered an individual inspite of his changes over time.

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Frames

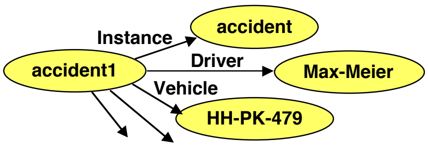
Frames have been proposed as knowledge representation structures for representing interrelated knowledge in larger units.

Marvin Minsky: "A Framework for Representing Knowledge", 1975

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

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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

- Inbuilt inference services enriched by demon procedures

<u>Example</u>:

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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Constraints

Constraints express restrictions on the values of variables.

Given variables and constraints, a constraint satisfaction problem (CSP) is the task of assigning values to the variables such the constraints are satisfied.

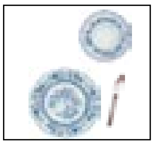
Constraints are useful for knowledge representation and inferencing:

- Constraints may provide a compact representation for n-ary relations

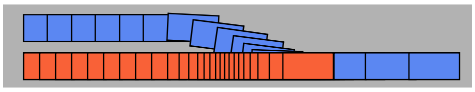
  Example: sum(action1.duration, action2.duration, action3.duration) ≤ 120 sek

- Spatial and temporal constraints are important for scene interpretation

Is this a cover?



Is this a forced brake ("Ausbremsen")?



- There exist efficient algorithms for solving special CSPs
- Constraints support flexible interpretation strategies

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Constraints for Scene Interpretation (1)

Constraints may model conceptual knowledge:

properly-parked-car-group	
parts:	f-car is-a car
	b-car is-a car
	r-car is-a car
constraints:	behind (b-car, f-car)
	behind (r-car b-car)
	distance (f-car b-car) ≥ 30cm
	distance (r-car b-car) ≥ 30cm

Constraints may express concrete knowledge about a scene:

length(car1) ≤ 300cm
behind (car1, car2)
behind (car3, car2)
distance (car1, car2) = 42cm
distance (car3, car2) ≥ 400cm

Constraints may express inferred knowledge about a scene:

behind (car3, car1)
distance (car3, car1) ≥ 100cm

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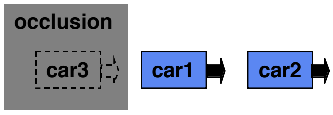
Constraints for Scene Interpretation (2)

Constraints may restrict hypotheses:

```
properly-parked-car-group1
parts:          car2 is-a car
                car1 is-a car
                car3 is-a car
constraints:    behind (car1, car2)
                behind (car3, car1)
                distance (car1, car2) = 42cm
                distance (car3, car1) ≥ 30cm
```



car3 is not visible but may be hypothesized

Constraints may help to focus processing:

behind (car3, car1)

scene analysis may be focussed on "behind"-region

Hard and Soft Constraints

- **Hard constraints <u>must</u> be satisfied. A violated constraint prohibits a solution. The CSP is a satisfiability problem.**
- **Soft constraints <u>should</u> be satisfied. A violated constraint impairs the quality of a solution. The CSP is an optimization problem.**

Constraints relevant for scene interpretation may have different origin:

Constraints arising from logics

Examples:
- to be "relatives" persons must have a common ancestor
- "same-object-as" requires that two objects are identical
- "touches" implies "near"

Constraints arising from physical laws

Examples:
- an object may not be at different places at the same time
- different solid objects may not occupy the same place at the same time
- "holding" requires that the holder is physically connected to the held object

Constraints arising from conventions

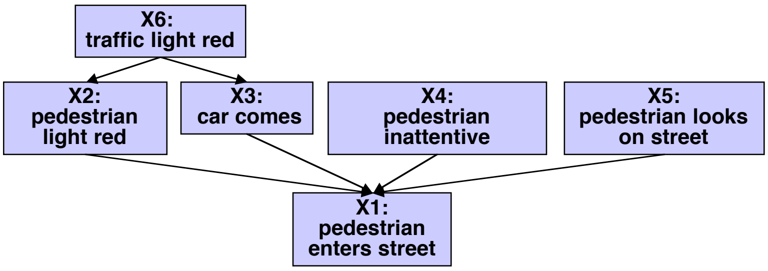
Examples:
- spatial constraints for a "cover"
- temporal constraints for a typical "overtake"
- actions for inserting a CD into a CD-player

Joint Probability Distributions

A joint probability distribution specifies co-occurrence probabilities of instances of random variables.

$P(X=a, Y=b, Z=c) = p_{abc}$ <=> co-occurrence of a, b, c has probability p_{abc}

Bayesian networks (Bayes nets, belief nets) are special representations of joint distributions in terms of directed acyclic graphs where links specify causal influences.



Bayes nets are valuable because of associated inferencing methods

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Joint Probability Distributions and Constraints

A probability distribution over a set of random variables may be viewed as a specification of individual soft constraints:

Constraint specified by relation $R \subseteq X \times Y \times Z$ <=>

Co-occurrence of a, b, c is prohibited if $(a\ b\ c) \notin R$

Finding the most probable values for random variables given evidence can be viewed as finding a solution with the "best" constraint satisfaction.

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