Last time: Object-oriented knowledge representation

- Facts are statements about concrete things (instances, entities, object, frame instance…)
- General knowledge statements assert the existence of concepts/classes/entity types/frames and relationships between them.
- Predicate logic, entity-relationship modelling, object-oriented programming languages etc. all take such an object-oriented view.
  - The underlying assumptions are related to the suitability of understanding and describing the world as instances, concepts, and relationships between these; and that it is easy for humans to express their knowledge in this way.
- Core modelling constructs are:
  - Inheritance
  - Generalisation / subsumption hierarchies (classes can be hierarchic)
  - Part-whole relationships
  - Event, role
  - Type constraints

Graphs

Institute for Interactive Systems and Data Science

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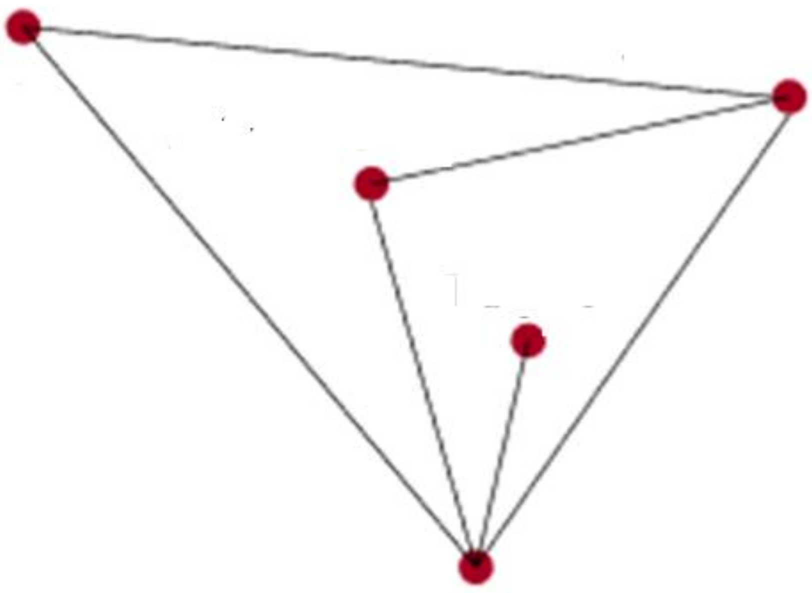
Learning Goals

- Define different types of graphs (labelled or not, directed or not)
- Understand semantic networks
- Understand relationship between graphs, semantic networks, and logic.
- Explain and use spreading activation to find related entities
- Explain common graph measures (shortest path, centrality, between-ness, connectedness)
- Understand graph measures as ways to reason over graphs and semantic networks

What is a Graph?

Structure that consists of vertices (nodes) and edges.

- Vertices and edges can have labels (labelled graph), or not (unlabeled graph)
- Edges can have a direction (directed graph), or not (undirected graph).

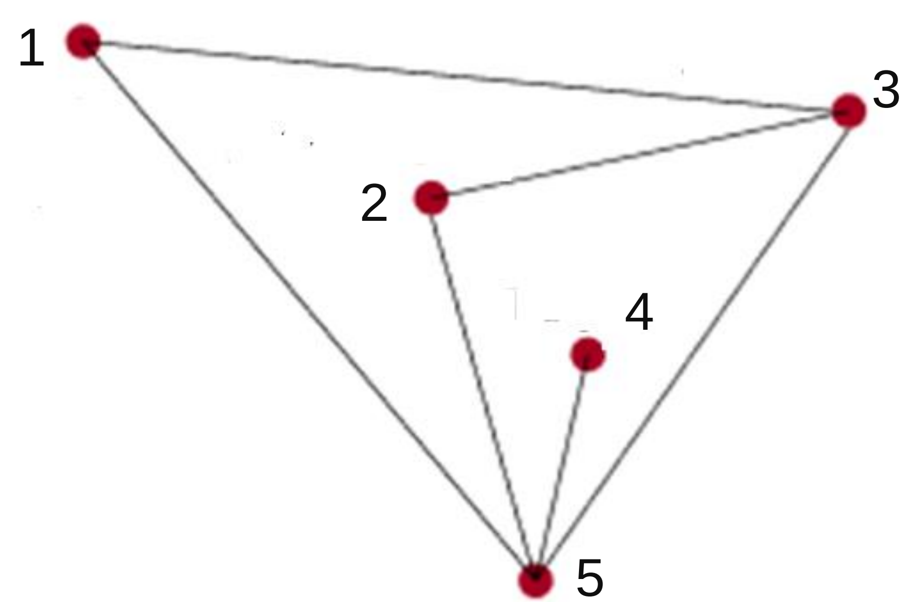


Graph representation as adjacency matrix

	1	**2**	**3**	**4**	**5**
1	0	0	1	0	1
2	0	0	1	0	1
3	1	1	0	0	1
4	0	0	0	0	1
5	1	1	1	1	0

Adjacency matrix A

- i = row-index
- j = column-index
- A(i,j) = number of edges e(i,j)
- Uniquely represents the graph



Knowledge graphs

Represent general knowledge

Semantic Networks

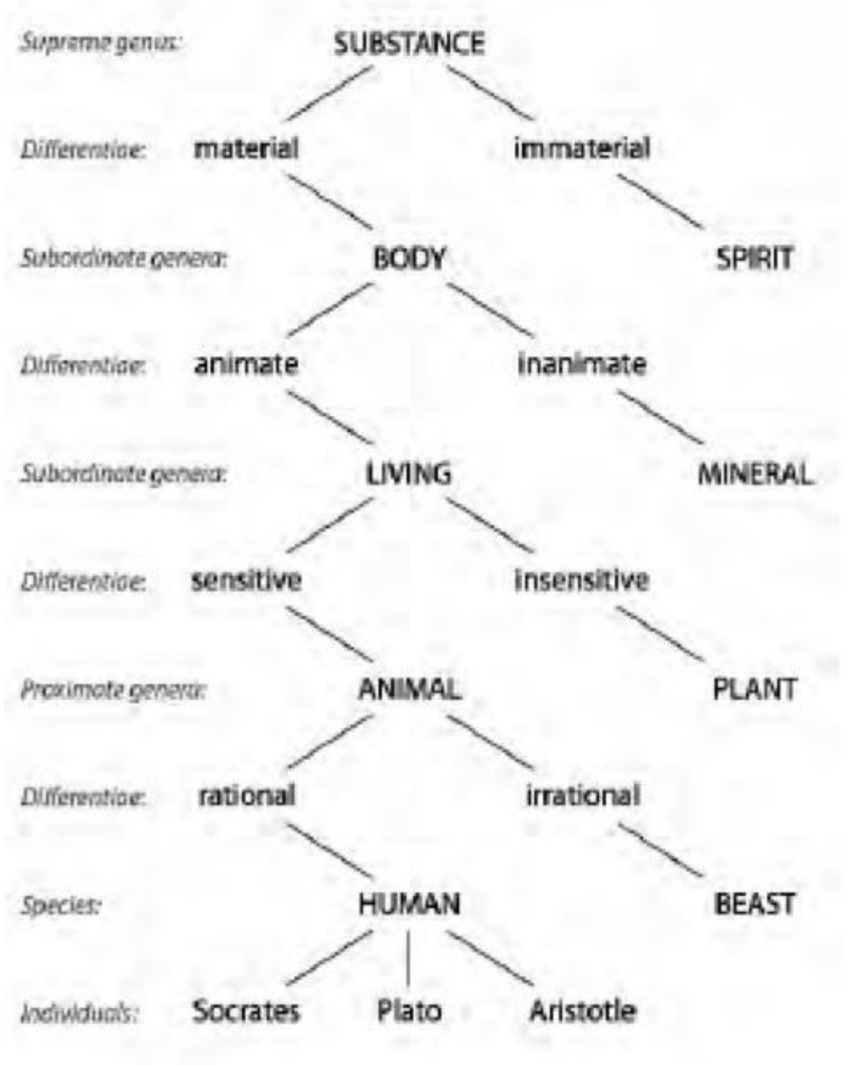
- Labelled directed graphs (vertices, edges, labels)
- **Semantics** (meaning) associated with labels (special labels, like „is_a“, or „is_parts_of“)
- **Procedures** that implement inferencing on semantic networks

Different types of semantic networks; hybrids exist

- Assertional networks
- Definitional networks (~taxonomies, ontologies)
- Implicational networks (describing beliefs, causalities, inferences)

Semantic Network – Example Tree of Porphyry (300 CE)

Idea: Classify everthing that exists in natural life



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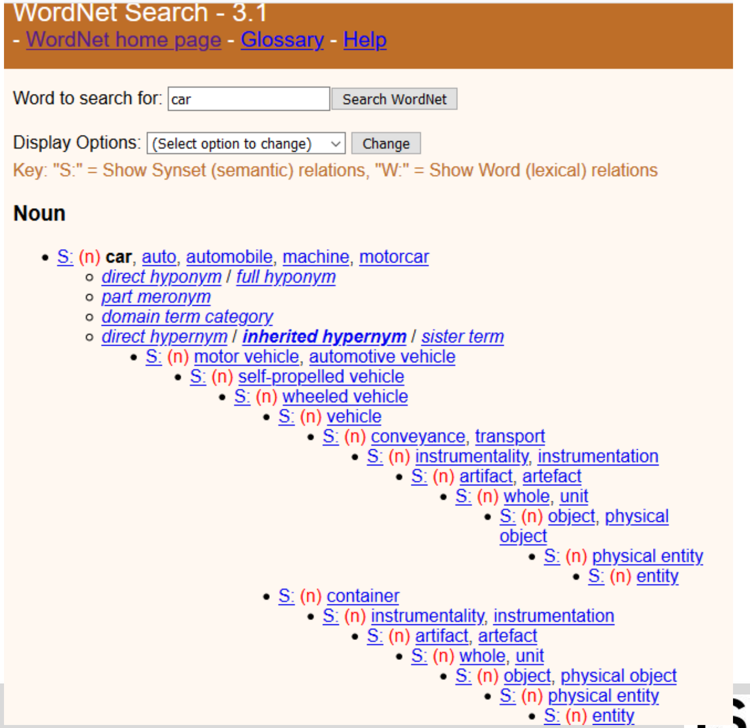
Semantic Network – Example WordNet

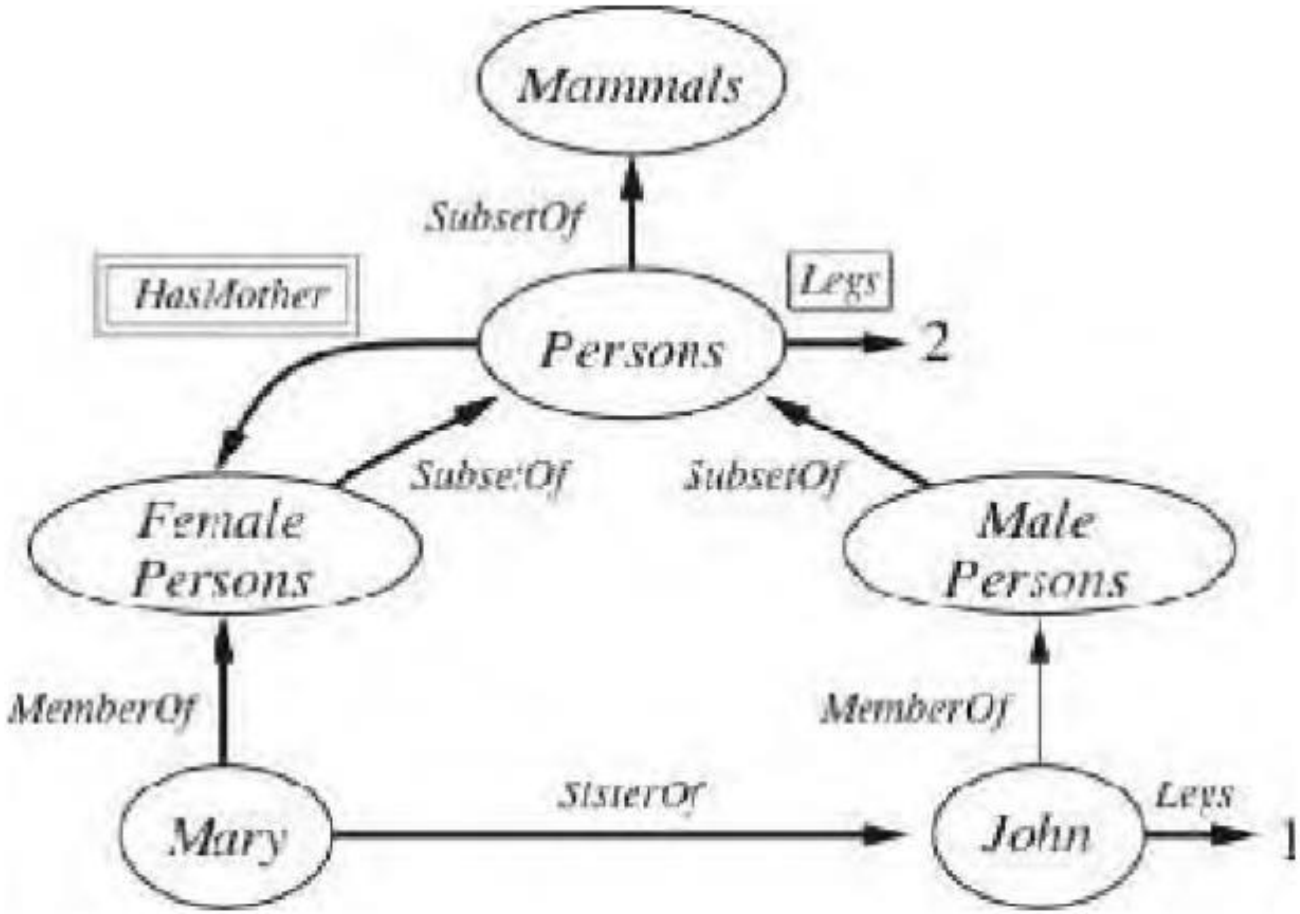
WordNet: Lexical database of English

- Concepts are nodes
- Concepts can be expressed by multiple words, with the relationship “synonym”
- Concepts are related to by semantic relationships, e.g., generalization, aggregation

https://wordnet.princeton.edu/ - „Use WordNet Online“



Semantic Network – Example, graphic representation (based on Russell & Norvig – AI, 3rd Edition, Ch. 12.5.1)



Semantic Network – Example, logic representation (based on Russell & Norvig – AI, 3rd Edition, Ch. 12.5.1)

- $FemalePersons(x) \rightarrow Persons(x)$
- $MalePersons(x) \rightarrow Persons(x)$
- $Persons(x) \rightarrow Mammals(x)$
- $Persons(x) \rightarrow \exists y\text{:}\, hasMother(x, y) \wedge FemalePersons(y)$
- $Persons(x) \rightarrow Legs(x, 2)$
- FemalePersons(Mary)
- MalePersons(John)
- sisterOf(Mary,John)
- Legs(John,1)

Semantic Networks as Knowledge Representation

- Semantic Networks were invented as a new and „more natural“ type of knowledge representation
- …. turned out, it could be arbitrarily formal or informal
  - **Informal** (see examples on Slides 11 and 12): Represent any kinds of relationships between concepts in the form of a semantic network
  - **Formal** (see example on Slides 13 and 14): Represent logic statements in the form of a semantic network

Reasoning over graphs

to infer further knowledge about the instances, concepts, and their relationships which are represented by the graph

Reasoning over Semantic Networks with Logic-Based Semantics

- Might be possible to use simpler reasoning to answer queries:

Example queries for Example on Slide 13:
- How many legs does John have?
- How many legs does Mary have

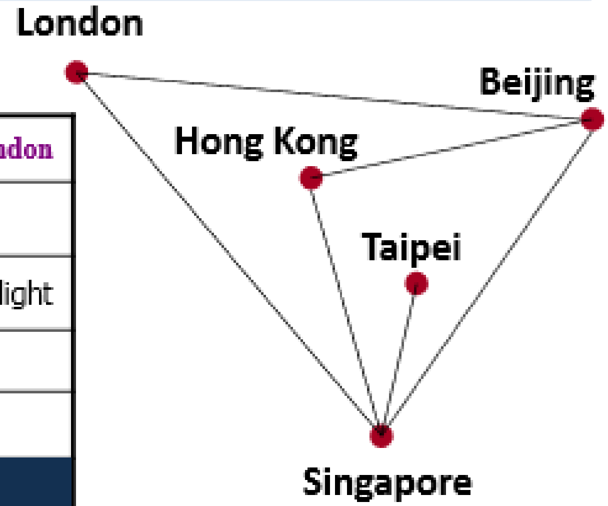
Answer query by: Start from instance node, travel up the hierarchy to the first outgoing relationship "Legs", and take value at the end.
- Simple, can deal with default values and deviations from default values; gets complex in cases of complex inheritance and subsumption hierarchies.

Data graphs

Structure data, represent facts (relationships between instances)

Graphs – Example Flight Connections

From\To	Hong Kong	Singapore	Beijing	Taipei	London
Hong Kong		4 Flights			
Singapore	2 Flights		3 Flights	1 Flight	1 Flight
Beijing	1 Flight	2 Flights			
Taipei					
London		1 Flight	1 Flight		

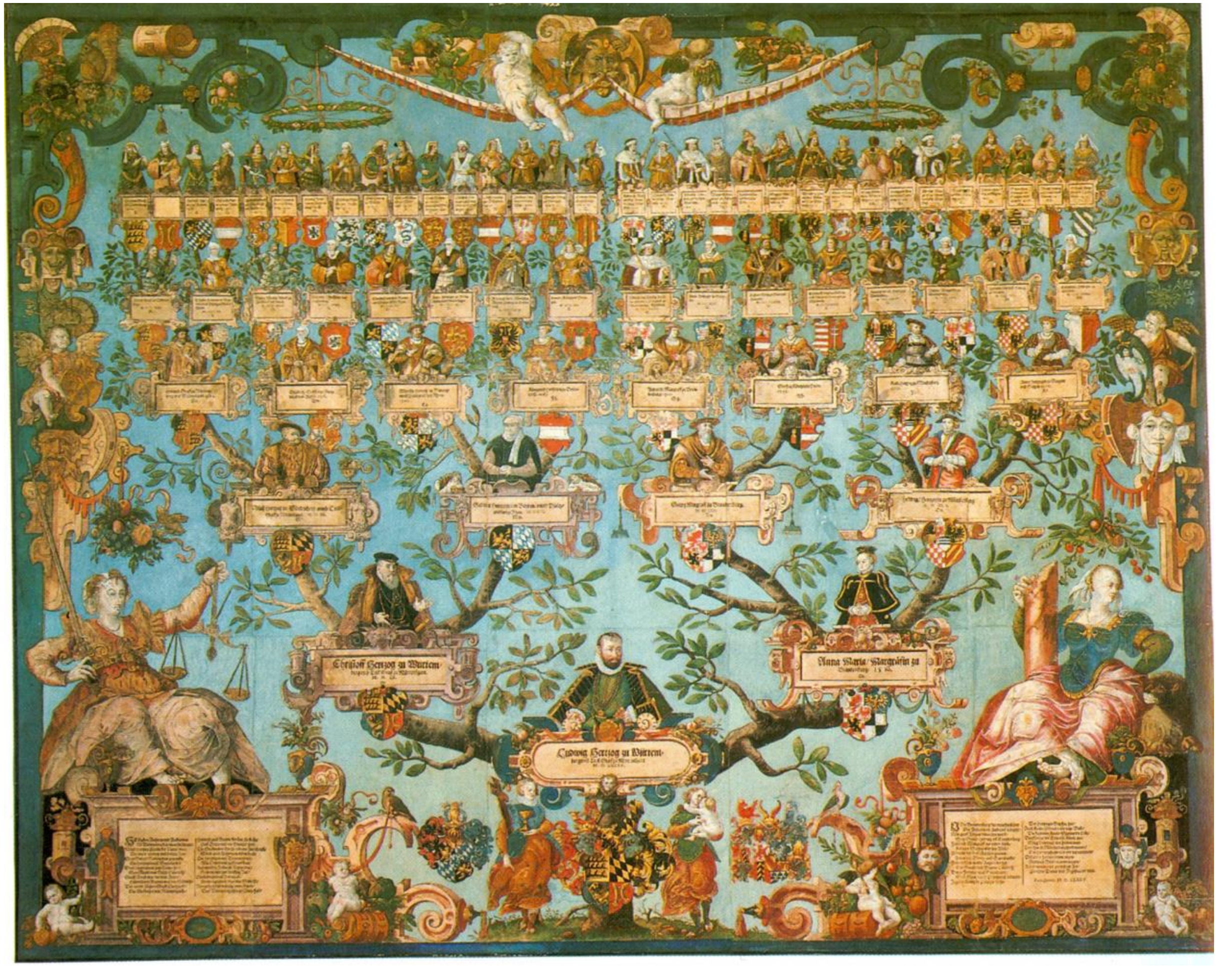


Draw a graph to see whether there are direct flights between any two cities (in either direction)

Picture from F. Oggier's Discrete Mathematics: http://www1.spms.ntu.edu.sg/~frederique/dm11.pdf

Which other examples can you think of – what could well be represented as a graph?

Graphs – Example “Ahnentafel Herzog Ludwig”



By Jakob Lederlein - eingescannt aus: Robert Uhland (Hrsgb.): 900 Jahre Haus Württemberg, 3. Aufl., Stuttgart 1985, ISBN 3-17-008930-7, S. 158, Public Domain, https://commons.wikimedia.org/w/index.php?curid=1997456

Graphs – Web science and scientometrics as examples

- In web science: Webgraph – websites as vertices, and links as edges.
- In scientometrics: Citation networks - scientific publications as vertices, and references as edges; co-author networks – scientists as vertices, co-authorships as edges

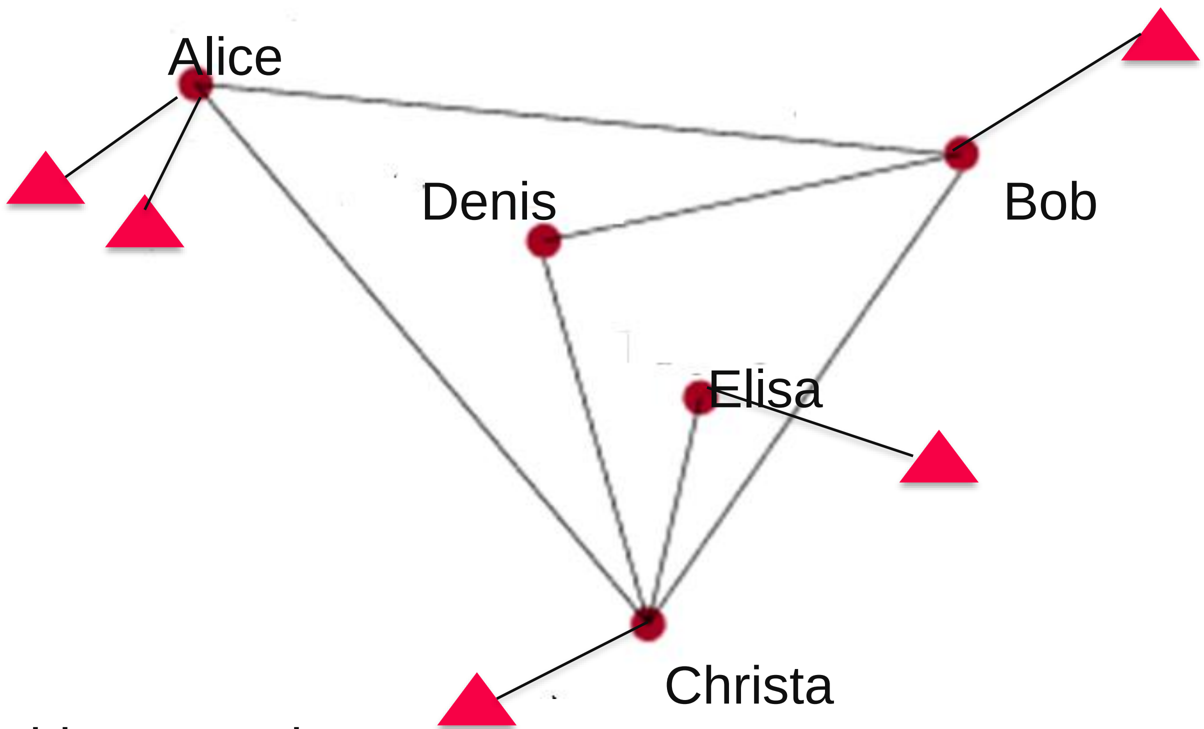
In the above examples, graphs represent knowledge about individual (concrete entities); they represent data.

Reasoning over graphs with graph-specific algorithms

to infer further knowledge about the instances, concepts, and their relationships which are represented by the graph

Spreading activation

Spreading Activation 1



Relationship semantics:

- connection via social software between people
- connection “hasLikedRecently” of posts, links, …

Spreading activation 2

Given

- Graph
- Set of initial activated nodes, each with an activation value. Max (typically)=1; min (typically)=0
- Activation threshold value, above this, a node fires
- Decay value D
- Termination criteria (differ, e.g., a fixed number of cycles, no firing in a cycle)

When a node *i* fires at *t1*, for all connected nodes *j*, with *A(i,j)* the weight of the edge between *i* and *j*:

$$ActivationValue(j, t2) = ActivationValue(j,t1)+ActivationValue(i,t1)*A(i,j)*D$$

Spreading activation 3

What questions can we answer with spreading activation?

- What are similar / close nodes?
  - Used in information retrieval (graphs contain documents and metadata)
- Modelling propagation: Where will sth. Spread out to? (Information, virus)

Using graph measures for reasoning

Typical graph measures used to reason over graphs as knowledge representation

(Shortest) Path: What is the relationship between v1 and v2

Centrality: What are the most important concepts or individuals represented in the graph?

- Most influential persons in a social network, key infrastructure nodes in the Internet, super-spreaders of disease, …

Path and shortest path

Path between v_1 and v_n: Sequence of vertices (v_1, v_2 , … v_n), all v_i are different, such that edges (v_i , v_{i+1}) exist in the graph.

Shortest path – minimises the weights of constituent edges

- What edge weight is needed for shortest path to correspond to the path with the fewest edges?

Interpretation in KR: What is the relationship between two vertices?

Centrality

There isn‘t the one and only centrality measure.
Centrality measures are often application specific.

Examples

- **Degree centrality** = how many incoming connections in one node
  CD(v)=deg(v) – the centrality of vertex v is its degree
- **Closeness centrality** = the closer a node is to all other nodes, the more central

$CC(x) = \frac{N}{\sum_y d(y,x)}$ … where d(y,x) is the length of the shortest path between x and d; and N is the number of nodes in the graph

References

- Graph Theory: http://www1.spms.ntu.edu.sg/~frederique/Teaching.html (scroll down to Discrete Mathematics, Chapter 11 of this course).
- Russell, S. & Norvig, P. Artificial Intelligence – A Modern Approach, 3rd Edition.

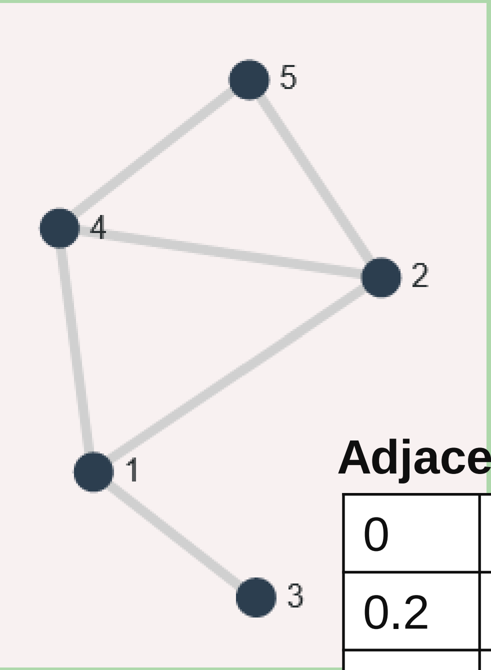
Exercise 6

Exercise

- Identify the individuals and the concepts in the semantic network on Slide 13.
- Identify the core modelling constructs from the last lecture in the semantic network on Slide 13.
  - Inheritance, generalization, aggregation or composition, association, type constraints
- Take a look at the graph on slide 14. How could we express that Mary has only 1 leg?

Exercise 7

Exercise



Adjacency Matrix

0	0.2	0.8	0.8	0
0.2	0	0	0.8	0.8
0.8	0	0	0	0
0.8	0.8	0	0	0.3
0	0.8	0	0.3	0

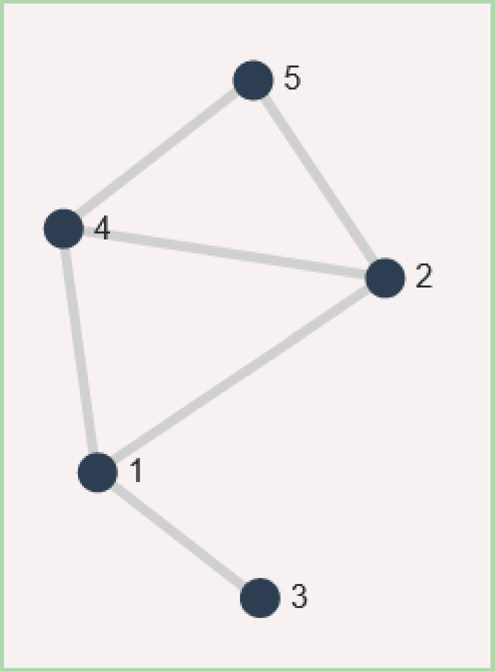
The vertices in the graph are documents. The weight on the edges represents a mix of document similarity and association in terms of users opening the documents closely „next“ to each other in terms of time.

A user opens document 1.

Which other document should an intelligent document viewer recommend to the user? (Choose document with highest value)

Answer this question by using spreading activation: Initial value of vertex 1=1; Stop after two cycles; Decay factor: 0.5; Firing threshold=0.3

Exercise



Adjacency Matrix

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0.2	0	0	0.8	0.8
0.8	0	0	0	0
0.8	0.8	0	0	0.3
0	0.8	0	0.3	0

Node values

t=0					
t=1					
t=2					