EH2750 Computer Applications in Power Systems, Advanced Course.

Lecture 5

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Acknowledgement

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  Professor Rosenschein of the Hebrew University Jerusalem, Israel

  and

  Dr. Georg Groh, TU-München, Germany.

- Available at the Student companion site of the Introduction to Multi Agent Systems book

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Outline of the Lecture

- Repeating where we are right now
  - Intelligent Agents of various types
  - How to make agents think and plan
- Constraint Satisfaction Problems
  - A variant of planning problems (still in one agent)
- Multi-agent interactions
  - Some concepts for cooperation
- Agent Communication
  - Ontologies, XML, RDF and OWL

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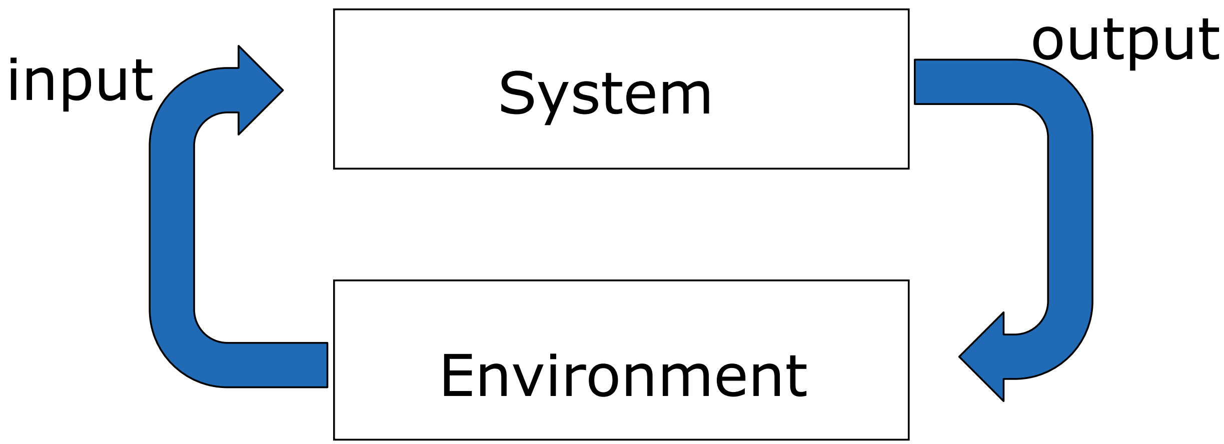
What is an Intelligent Agent?

- The main point about agents is they are *autonomous*: capable of acting independently, exhibiting control over their internal state
- Thus: *an intelligent agent is a computer system capable of flexible autonomous action in some environment in order to meet its design objectives*

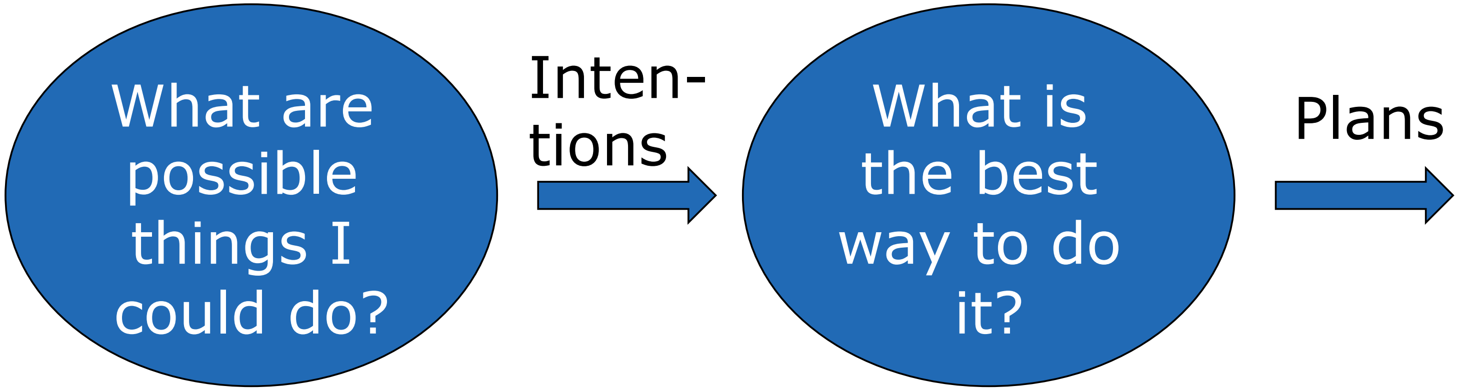


The discussion so far

- Chapter 2 describes the idea of agents that perform tasks in an environment and sets some definitions
- Chapters 3, 4, & 5 describe three different approaches to describing and developing the apparent Intelligence in the agents.
  - Chapter 3 – Deductive Reasoning Agents
  - Chapter 4 – Practical Reasoning Agents
  - Chapter 5 - Reactive (and Hybrid Agents)
- In the Excerpt from the AI book used in Lecture #4 we took a look at planning and searching
- Today we start looking at the Multi in Multi-agent systems

Practical Reasoning

- Human practical reasoning consists of two activities:
  - *deliberation*
    deciding *what* state of affairs we want to achieve
  - *means-ends reasoning*
    deciding *how* to achieve these states of affairs
- The outputs of deliberation are *intentions*

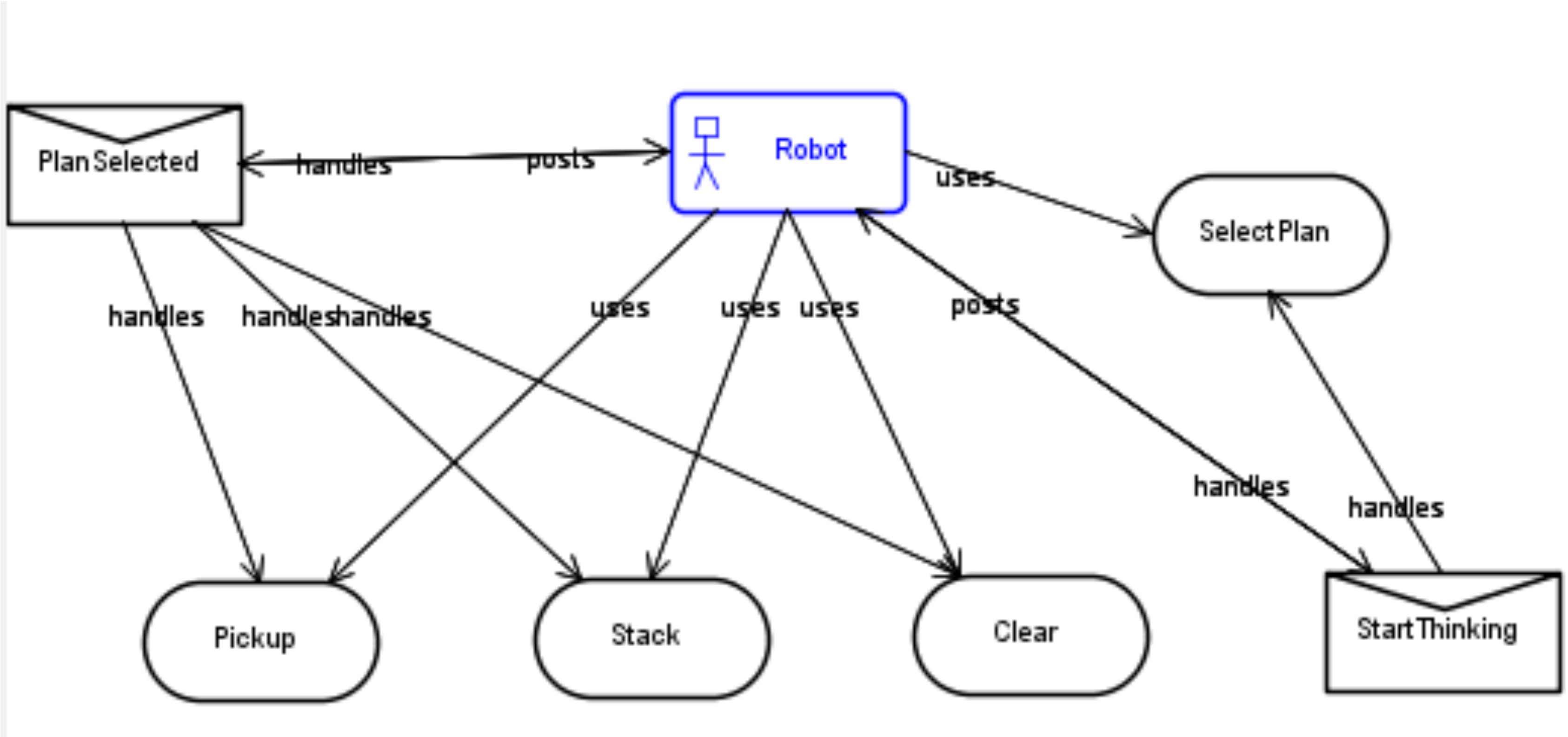


Practical Reasoning Agent

```
function SIMPLE-PROBLEM-SOLVING-AGENT(percept) returns an action
   inputs: percept, a percept
   static: seq, an action sequence, initially empty
           state, some description of the current world state
           goal, a goal, initially null
           problem, a problem formulation

   state ← UPDATE-STATE(state, percept)
   if seq is empty then do
      goal ← FORMULATE-GOAL(state)
      problem ← FORMULATE-PROBLEM(state, goal)
      seq ← SEARCH(problem)
   action ← FIRST(seq)
   seq ← REST(seq)
   return action
```

How this can look in JACK



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Constraint Satisfaction problems

- Formally, a Constraint Satisfaction Problem (CSP) is
  - A set of variables $x_1, x_2, \ldots x_n$
  - All within a domain $d_1, d_2, \ldots d_n$
  - A set of constraints $c_1, c_2, \ldots c_m$
- A set of assigned values (to one or more of) the variable(s) is a state.
  - E.g.
    - $x_1 = 23$, $x_2 = 3$ is the state {23,3}

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Solution to a CSP

1. All variables have been assigned a value from their respective Domain – *complete assignment*

2. All constraints hold – *consistent assignment*

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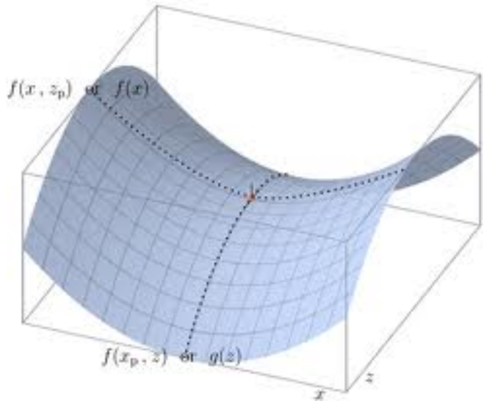
CSP – Different Characteristics

- Discrete variables with Finite Domains
  - Map colouring (typical example)
  - Circuit switching



- Infinite domains
  - E.g. Scheduling of flights

- Continuous variables
  - Linear constraints – optimisation problem….

$$\begin{array}{ll} \underset{x}{\text{minimize}} & f(x) \\ \text{subject to} & g_i(x) \leq 0, \quad i = 1, \ldots, m \\ & h_i(x) = 0, \quad i = 1, \ldots, p \end{array}$$

CSP in discrete finite domains

- Classic example – map coloring

Solutions are assignments satisfying all constraints, e.g.,
$\{WA = red, NT = green, Q = red, NSW = green, V = red, SA = blue, T = green\}$

- Color the map of Australia
- Using the colors Red, Green, Blue
- No neighbours can have the same color
- CSP formulation
  - x_i = color of state i
  - D = {Red, Green, Blue, Null}
  - $x_i \neq x_j$ if $x_i = N(x_j)$

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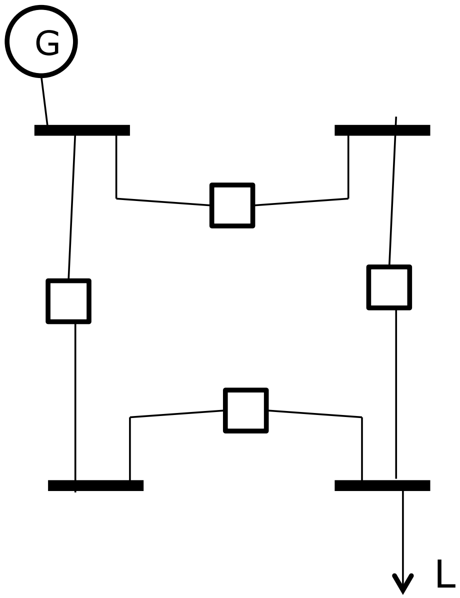
Or, if you wish

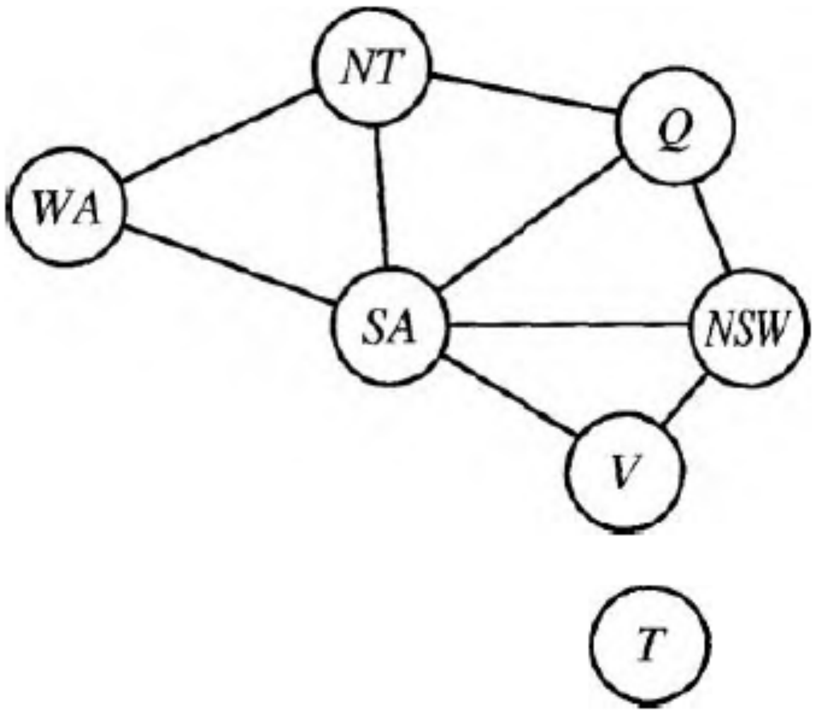
- CSP formulation for Switching problem



- Supply all load in the grid
- Switches can be on or off
- No loops
- CSP formulation
  - x_i = state of Switch i
  - D = {breaking, conducting, Null}
  - c_1 = not($x_1 \wedge x_2 \wedge x_3 \wedge x_4$)

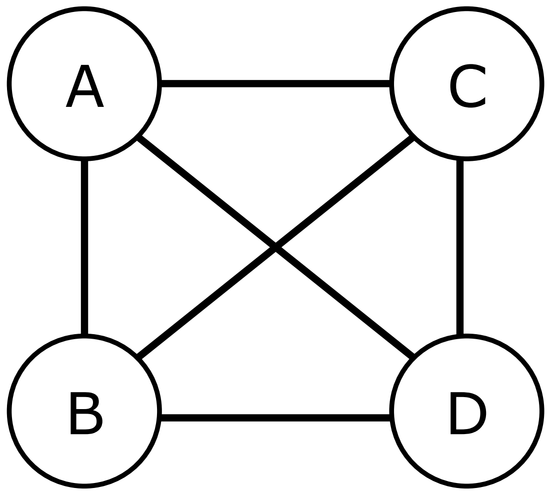
Back to Australia

- Constraint Graph for Australia coloring problem



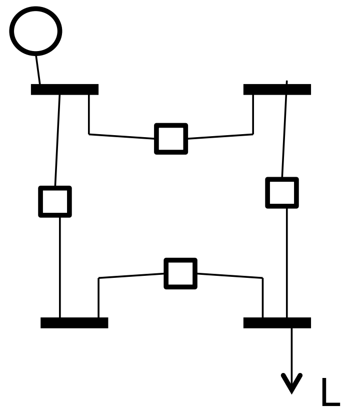
- It turns out, that the structure of the problem can be useful for finding the solution.
- This includes studying the types and degrees of constraints.

And the Switching problem



Types of constraints

- Unary constraints involve a single variable e.g.,
  - `SA ≠ green`
- Binary constraints involve pairs of variables
  - `SA ≠ WA`
- Higher order involves 3 or more variables
  - $\texttt{not}(x_1 \wedge x_2 \wedge x_3 \wedge x_4)$
- More advanced constraints
  - Use cost metrics for a variable
    - Powerflows for instance?
  - Constrained optimization problem



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So, why all this?

- CSPs can be seen as search problems
  - States are defined by values assigned this far
    - Initial state: empty assignment {}
    - Successor function:
      - Assign value to a variable that is OK with constraints
    - Goal test: complete assignment with all constraints satisfied

- Note that every solution appears at depth n

  ➔use depth-first search

But, wait – don’t be too fast

- What is the complexity of a completely naive solution?

$$O(n!d^n)$$

- Because for every variable you must test any color and then test the constraints and goal fulfilment.

- But that is stupid!

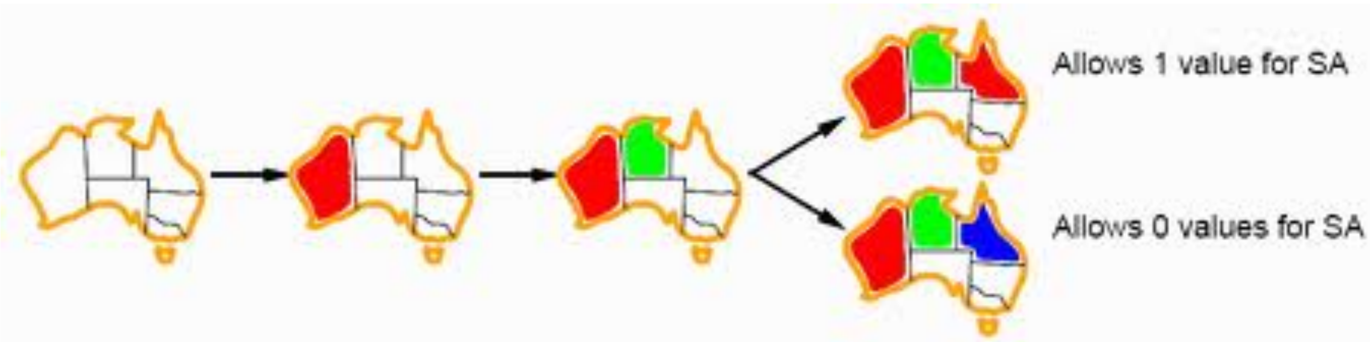
Commutativity

- The order in which assignments are made is not important.
- Consider only one variable at each node.
  - No point to worry about color of WA when you are selecting the color at SA
- Use Backtracking if searching fails.
  - Success function is:
    - Assign value to variable x_i from d_i
    - If not possible unless constraints are broken
      - Go back to x_{i-1} and assign alternate value from domain d_{i-1}

"Generic" Heuristics

- Based on our knowledge of the constraint graph we can choose which is the next node to assign a variable to.

- Minimum Remaining values (MRV)
  - Pick the Node with the least number of available values.
  - This avoids searching for solutions



Degree Heuristic

- But where to start?
  - Select the Node with the most constraints, highest degree* in constraint graph.

** Number of connecting edges in the Graph.*

Backtracking Search

```
function BACKTRACKING-SEARCH(csp) returns a solution, or failure
  return RECURSIVE-BACKTRACKING({ }, csp)

function RECURSIVE-BACKTRACKING(assignment, csp) returns a solution, or failure
  if assignment is complete then return assignment
  var ← SELECT-UNASSIGNED-VARIABLE(VARIABLES[csp], assignment, csp)
  for each value in ORDER-DOMAIN-VALUES(var, assignment, csp) do
     if value is consistent with assignment according to CONSTRAINTS[csp] then
        add {var = value) to assignment
        result ← RECURSIVE-BACKTRACKING(assignment, csp)
        if result ≠ failure then return result
        remove {var = value) from assignment
  return failure
```

Figure 5.3 A simple backtracking algorithm for constraint satisfaction problems. The algorithm is modeled on the recursive depth-first search of Chapter 3. The functions *SELECT-UNASSIGNED-VARIABLE* and *ORDER-DOMAIN-VALUES* can be used to implement the general-purpose heuristics discussed in the text.

Things to take away

- Constraint Satsifaction Problems can be solved as searches
- Analysis of the problem structure can provide us with generic heuristics
- Planning with Backtracking is a key method for <u>cooperative planning</u>

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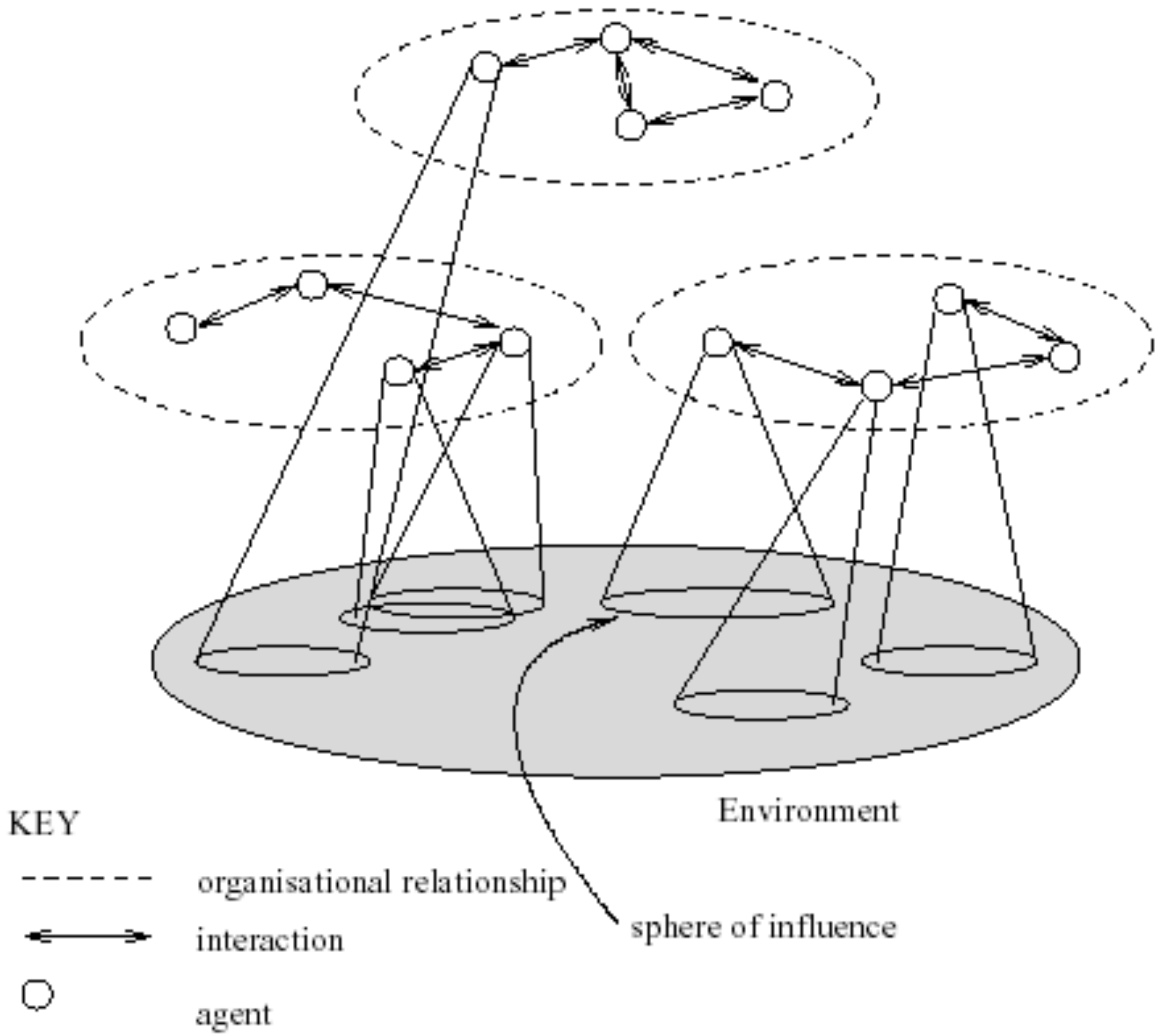
Multi-agent Systems



Multi-agent Systems

Contains a number of agents…

- …which interact through communication…
- …are able to act in an environment…
- …have different “spheres of influence” (which may coincide)…
- …will be linked by other (organizational) relationships

Working Together

- Why and how do agents work together?

- Important to make a distinction between:
  - *benevolent agents*
  - *self-interested agents*

Benevolent Agents

- If we “own” the whole system, we can design agents to help each other whenever asked
- In this case, we can assume agents are *benevolent*: our best interest is their best interest
- Problem-solving in benevolent systems is *cooperative distributed problem solving* (CDPS)
- *Benevolence simplifies the system design task enormously!*

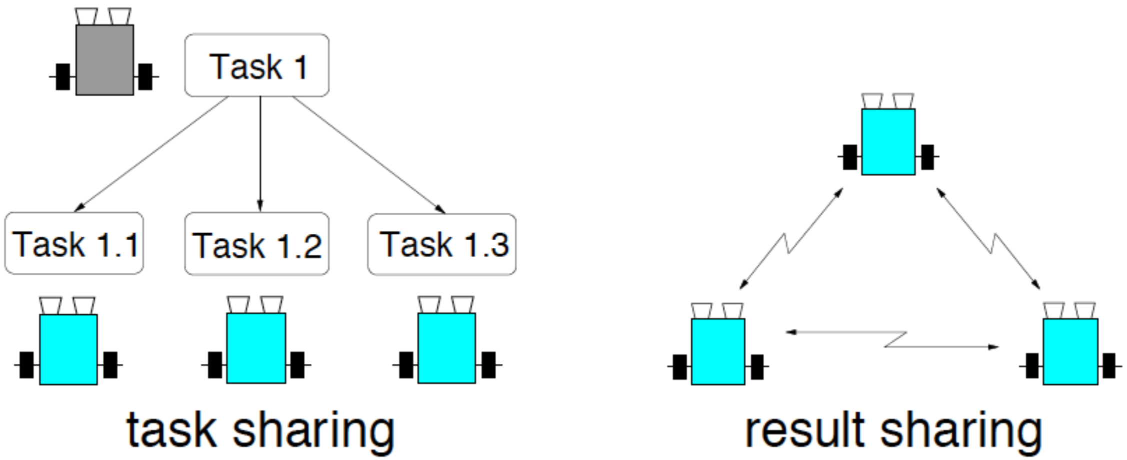
Self-Interested Agents

- If agents represent individuals or organizations, (the more general case), then we cannot make the benevolence assumption
- Agents will be assumed to act to further their own interests, possibly at expense of others
- Potential for *conflict*
- May complicate the design task enormously

Benevolent Agents

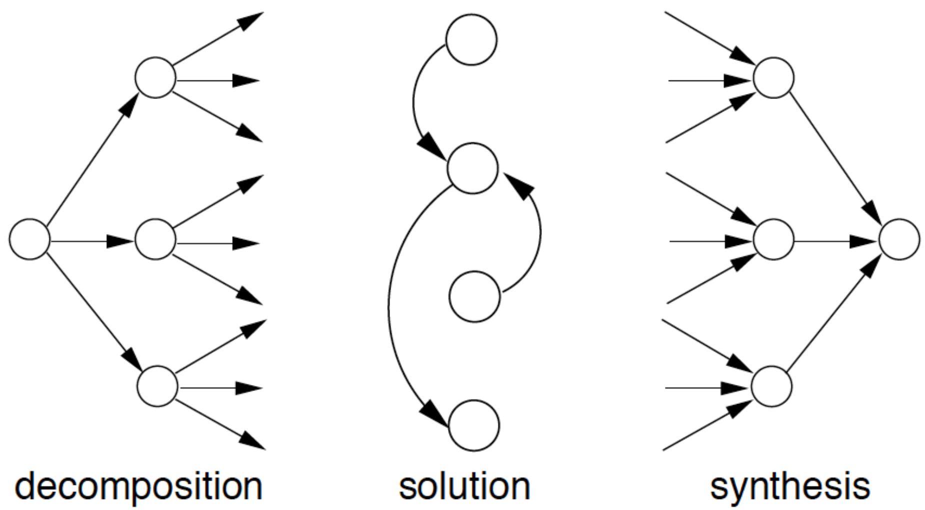
Task Sharing and Result Sharing

- Two main modes of cooperative problem solving:
  - *task sharing*:
    components of a task are distributed to component agents
  - *result sharing*:
    information (partial results, etc.) is distributed



Benevolent Agents
Cooperative Distributed Problem Solving

- CDPS is concerned with investigation of:
  - Problem subdivision
  - Sub-Problem distribution
  - Result synthesis
  - Optimization of problem solver coherence
  - Optimization of problem solver coordination



Benevolent Agents

Coherence

Coherence: Refers to “how well the MAS behaves as a unit along some dimension of evaluation”. Coherence may be measured in terms of

- Solution quality
- resource usage
- conceptual clarity of operation
- performance degradation if unexpected failure occurs

Benevolent Agents

Coordination

- ***Coordination:*** "The degree...to which [the agents] can avoid 'extraneous' activity [such as] ...synchronizing and aligning their activities"

→ Poor coordination if

  - Agents clobber each other's sub-goals
  - Lots of communication (no mutual predictability (e.g. by expressive models of each other))
  - Destructive interference if conflict

Self-Interested Agents

Utilities and Preferences

- Assume we have just two agents: $Ag = \{i, j\}$
- Agents are assumed to be *self-interested*: they *have preferences over how the environment is*
- Assume $\Omega = \{\omega_1, \omega_2, \ldots\}$ is the set of "outcomes" that agents have preferences over
- We capture preferences by *utility functions*:

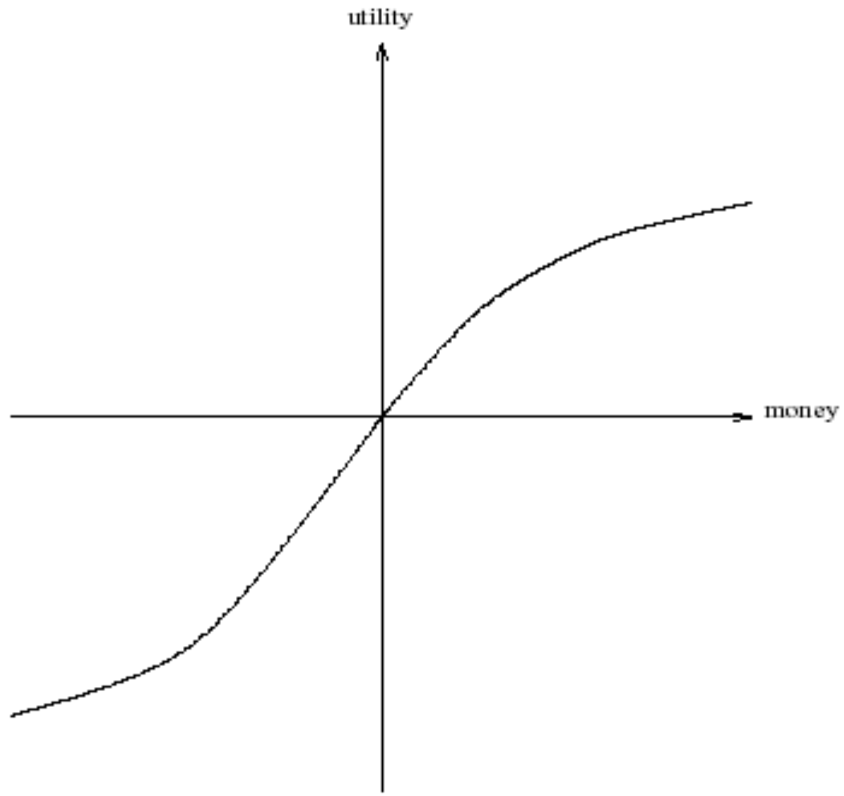
$$u_i = \Omega \to \mathbf{R}$$
$$u_j = \Omega \to \mathbf{R}$$

- Utility functions lead to *preference orderings* over outcomes:

$$\omega \succeq_i \omega' \text{ means } u_i(\omega) \geq u_i(\omega')$$
$$\omega \succ_i \omega' \text{ means } u_i(\omega) > u_i(\omega')$$

What is Utility?

- Utility is *not* money (but it is a useful analogy)
- Typical relationship between utility & money:



Multiagent Encounters

- We need a model of the environment in which these agents will act…
  - agents simultaneously choose an action to perform, and as a result of the actions they select, an outcome in Ω will result
  - the *actual* outcome depends on the *combination* of actions
  - assume each agent has just two possible actions that it can perform, *C* (“cooperate”) and *D* (“defect”)
- Environment behavior given by *state transformer function*:

$$\tau : \underbrace{Ac}_{\text{agent } i\text{'s action}} \times \underbrace{Ac}_{\text{agent } j\text{'s action}} \rightarrow \Omega$$

Multiagent Encounters

- Here is a state transformer function:

$$\tau(D,D)=\omega_1 \quad \tau(D,C)=\omega_2 \quad \tau(C,D)=\omega_3 \quad \tau(C,C)=\omega_4$$

(This environment is sensitive to actions of both agents.)

- Here is another:

$$\tau(D,D)=\omega_1 \quad \tau(D,C)=\omega_1 \quad \tau(C,D)=\omega_1 \quad \tau(C,C)=\omega_1$$

(Neither agent has any influence in this environment.)

- And here is another:

$$\tau(D,D)=\omega_1 \quad \tau(D,C)=\omega_2 \quad \tau(C,D)=\omega_1 \quad \tau(C,C)=\omega_2$$

(This environment is controlled by j.)

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Rational Action

- Suppose we have the case where *both* agents can influence the outcome, and they have utility functions as follows:

$$u_i(\omega_1) = 1 \quad u_i(\omega_2) = 1 \quad u_i(\omega_3) = 4 \quad u_i(\omega_4) = 4$$
$$u_j(\omega_1) = 1 \quad u_j(\omega_2) = 4 \quad u_j(\omega_3) = 1 \quad u_j(\omega_4) = 4$$

- With a bit of abuse of notation:

$$u_i(D,D) = 1 \quad u_i(D,C) = 1 \quad u_i(C,D) = 4 \quad u_i(C,C) = 4$$
$$u_j(D,D) = 1 \quad u_j(D,C) = 4 \quad u_j(C,D) = 1 \quad u_j(C,C) = 4$$

- Then agent i's preferences are:

$$C,C \succeq_i C,D \quad \succ_i \quad D,C \succeq_i D,D$$

- "*C*" is the *rational choice* for i.
  (Because i prefers all outcomes that arise through *C* over all outcomes that arise through *D*.)

Payoff Matrices

- We can characterize the previous scenario in a *payoff matrix*:

i

j		defect	coop
	defect	1 1	4 1
	coop	1 4	4 4

- Agent i is the *column player*
- Agent j is the *row player*

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Dominant Strategies

- Given any particular strategy (either *C* or *D*) of agent i, there will be a number of possible outcomes
- We say s_1 *dominates* s_2 if every outcome possible by i playing s_1 is preferred over every outcome possible by i playing s_2
- A rational agent will never play a dominated strategy
- So in deciding what to do, we can *delete dominated strategies*
- Unfortunately, there isn't always a unique undominated strategy

Nash Equilibrium

- In general, we will say that two strategies s_1 *and* s_2 are in Nash equilibrium if:
  1. under the assumption that agent i plays s_1, agent j can do no better than play s_2; and
  2. under the assumption that agent j plays s_2, agent i can do no better than play s_1.
- *Neither agent has any incentive to deviate from a Nash equilibrium*
- Unfortunately:
  1. *Not every interaction scenario has a Nash equilibrium*
  2. *Some interaction scenarios have more than one Nash equilibrium*

Competitive and Zero-Sum Interactions

- Where preferences of agents are diametrically opposed we have *strictly competitive* scenarios
- Zero-sum encounters are those where utilities sum to zero:

$$u_i(\omega) + u_j(\omega) = 0 \qquad \text{for all } \omega \text{ in } \Omega$$

- Zero sum implies strictly competitive
- Zero sum encounters in real life are very rare … but people tend to act in many scenarios as if they were zero sum

The Prisoner's Dilemma

- Two men are collectively charged with a crime and held in separate cells, with no way of meeting or communicating. They are told that:
  - if one confesses and the other does not, the confessor will be freed, and the other will be jailed for three years
  - if both confess, then each will be jailed for two years
- Both prisoners know that if neither confesses, then they will each be jailed for one year

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The Prisoner's Dilemma

- Payoff matrix for prisoner's dilemma:

		i defect	*i* coop
j	defect	2 2	1 4
j	coop	4 1	3 3

- Top left: If both defect, then both get punishment for mutual defection
- Top right: If i cooperates and j defects, i gets sucker's payoff of 1, while j gets 4
- Bottom left: If j cooperates and i defects, j gets sucker's payoff of 1, while i gets 4
- Bottom right: Reward for mutual cooperation

The Prisoner’s Dilemma

- The *individual rational* action is *defect*
  This guarantees a payoff of no worse than 2, whereas cooperating guarantees a payoff of at most 1
- So defection is the best response to all possible strategies: both agents defect, and get payoff = 2
- But *intuition* says this is *not* the best outcome:
  Surely they should both cooperate and each get payoff of 3!

The Prisoner's Dilemma

- This apparent paradox is *the fundamental problem of multi-agent interactions*.
  It appears to imply that *cooperation will not occur in societies of self-interested agents*.
- Real world examples:
  - nuclear arms reduction ("why don't I keep mine. . . ")
  - free rider systems — public transport;
- The prisoner's dilemma is *present everywhere*.
- Can we recover cooperation?
  - Well, yes we can introduce auctions, negotiations and argumentation. More on this next lecture!

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Agent Communication

- The traditional computer sciences view on communication in concurrent systems is focused on solving synchronization of multiple processes.
- Example:
- Processes `p1` and `p2`; shared variable `v`;

    `p1` reads `v`;
    `p2` reads `v`;
    `p2` updates `v`;
    `p1` updates `v`;
    → updates by `p2` are lost;

Agent Communication II

Object oriented view on communication: Object `o2` invokes method `m` on object `o1`: Java: **`o1.m(arg)`**

- *`o2` has control* over invocation. `o1` must invoke `m`.

Agent view on communication: Agent `a2` asks (sends event in JACK) agent `a1` to perform action α. (`a2` makes a request).

- *`a1` has control* over whether it performs action α. Agents are autonomous.

Agent Communication III

- What agents can do:
  Perform communication acts
- Goal: Influence other agents:
  - To make them perform actions or
  - to make them believe something (change their belief)
- The receiving agent decides whether to perform action or believe proposition

Speech Acts

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- Most treatments of communication in (multi-) agent systems borrow their inspiration from *speech act theory*
- Speech act theories are *pragmatic* theories of language, i.e., theories of language use: they attempt to account for how language is used by people every day to achieve their goals and intentions
- The origin of speech act theories are usually traced to Austin's 1962 book, *How to Do Things with Words*

Speech Acts in the agent community

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- Based on the Speech Act theory, Agent Communication Languages have been developed.

- The two most known are
  - KQML - Knowledge Quesry Markup Language.
  - FIPA – ACL Agent Communication Language.

- These are not programming languages as such, but formalisations of communication acts that are useful to understand and specify agent interaction.

Speech Acts – some thoughts.

- Consider:
  - performative = request
    content = “the door is closed”
    speech act = “please close the door”
  - performative = inform
    content = “the door is closed”
    speech act = “the door is closed!”
  - performative = inquire
    content = “the door is closed”
    speech act = “is the door closed?”

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Agent Communication Languages

- We now consider *agent communication languages* (ACLs) — standard formats for the exchange of messages
- An early example of an ACL is KQML, developed by the ARPA knowledge sharing initiative
  KQML is comprised of two parts:
  - the knowledge query and manipulation language (KQML)
  - the knowledge interchange format (KIF)
- A later developed framework is the FIPA

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KQML and KIF

- KQML is an ‘outer’ language, that defines various acceptable ‘communicative verbs’, or *performatives* Example performatives:
  - `ask-if` (‘is it true that. . .’)
  - `perform` (‘please perform the following action. . .’)
  - `tell` (‘it is true that. . .’)
  - `reply` (‘the answer is . . .’)
- KIF is a language for expressing message *content*

FIPA

- More recently, the Foundation for Intelligent Physical Agents (FIPA) started work on a program of agent standards — the centerpiece is an ACL
- Basic structure is quite similar to KQML:
  - *performative*
    20 performative in FIPA
  - *housekeeping*
    e.g., sender, etc.
  - *content*
    the actual content of the message

FIPA, example of an performative

- Example:

```
(inform
      :sender               agent1
      :receiver    agent5
      :content     (price good200 150)
      :language    sl
      :ontology    hpl-auction
)
```

But this part then?

To communicate…

- …the agents must understand each other
- To understand each other the agents must use common terms, an *Ontology* is a formal specification of such terms.

Specifications of Terms - XML

- A basic format for specifying information exchange is the XML (eXtended Markup Language)

```xml
<?xml version="1.0" standalone="yes" ?>
- <shop location="Birmingham" size="Large">
  - <food>
      <Name>Apple</Name>
      <type>fruit</type>
      <cost>15</cost>
    </food>
  - <food>
      <Name>Carrot</Name>
      <type>vegetable</type>
      <cost>10</cost>
    </food>
  </shop>
```

- The structure of the information is decided by the author of the text file
- No rule checking is implemented in the format
- Data can be named with tags.
- The strucuture of the XML file is specified in an XML Schema (XMLS)
- By exchanging XMLS files, two agents can be made aware of possible terms.

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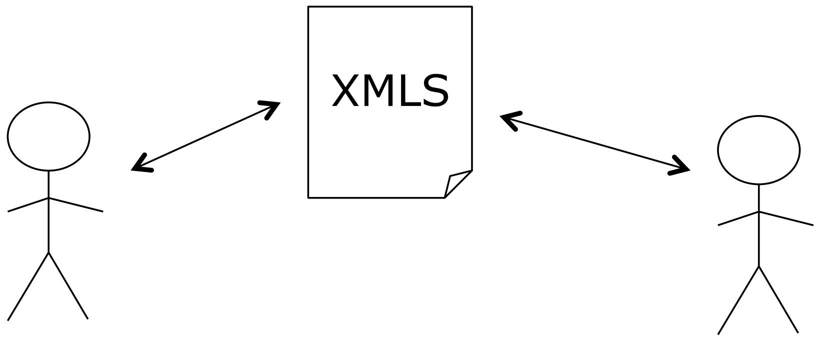
XML Schema

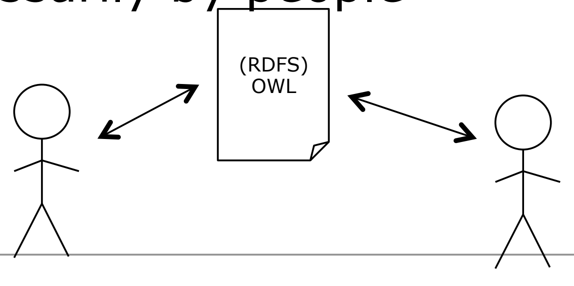
```
<xs:schema xmlns:xs="http://www.w3.org/2001/XMLSchema"
           xmlns:xdb="http://xmlns.oracle.com/xdb version=1.0">
<xs:element name="EmployeeDetails">
    <xs:complexType>
      <xs:sequence>
        <xs:element name="MailAddressTo">
          <xs:complexType>
            <xs:sequence>
              <xs:element name="EmployeeName" type="xs:string"/>
              <xs:element name="Department" type="xs:string"/>
              <xs:element name="Job" type="xs:string"/>
              <xs:element name="Salary" type="xs:string"/>
            </xs:sequence>
            <xs:attribute name="EmployeeId" type="xs:string" use="required"/>
          </xs:complexType>
        </xs:element>
      </xs:sequence>
    </xs:complexType>
</xs:element>
</xs:schema>
```



Specifications of Terms - RDF

- Resource Description Framework uses XML syntax but adds more rules to the terms.
  - XML is more flexible = Less interoperable
  - RDF is more strucutred)= More interoperable

- A framework (not a language) for describing resources
  - Providing a model for data
  - Syntax to allow exchange and use of information stored in various locations
  - The point is to facilitate reading and correct use of information by *computers*, not necessarily by people



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RDF Structure

- Described in RDF Schema (or now more popular OWL)
- Nodes are identified by URIs
  - E.g. http://iec.ch/TC57/2001/CIM-schema-cim10#Wires
- Elements in RDF files can be given more attributes
  - rdfs:Class
  - rdfs:Property
  - rdfs:subClassOf
  - rdf:type

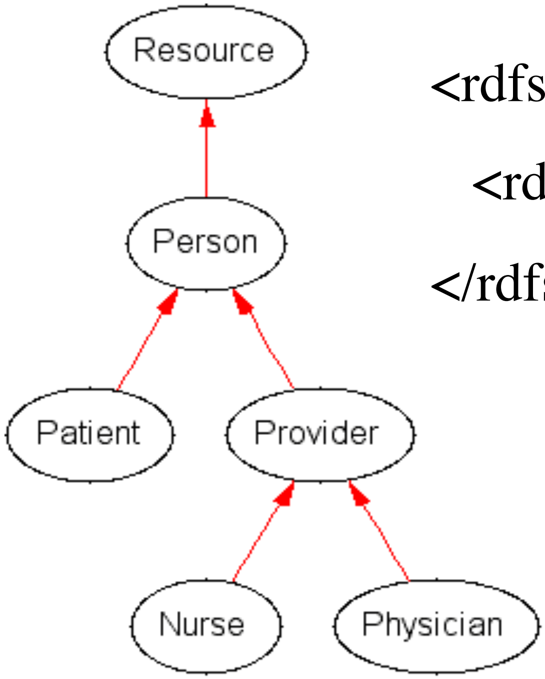
```
<rdfs:Class rdf:ID="Switch">
   <rdfs:label>Switch</rdfs:label>
   <rdfs:subClassOf
rdf:resource="#ConductingEquipment"/>
</rdfs:Class>

<rdfs:Class rdf:ID="Breaker">
   <rdfs:label>Breaker</rdfs:label>
   <rdfs:subClassOf rdf:resource="#Switch"/>
</rdfs:Class>

 <rdf:Property rdf:ID="Switch.NormalOpen">
   <rdfs:label>NormalOpen</rdfs:label>
   <rdfs:domain resource="#Switch"/>
   <rdfs:range rdf:resource="#Boolean"/>
</rdf:Property>

<rdf:Property rdf:ID="Breaker.AmpRating">
   <rdfs:label>AmpRating</rdfs:label>
   <rdfs:domain resource="#Breaker"/>
   <rdfs:range rdf:resource="#Real"/>
</rdf:Property>
```

Simplified Schema, Healthcare example



<rdfs:Class rdf:ID="Provider">

<rdfs:subClassOf rdf:resource="#Person"/>

</rdfs:Class>

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RDF example

The **xmlns:rdf** namespace, specifies that elements with the rdf prefix are from the namespace "http://www.w3.org/1999/02/22-rdf-syntax-ns#".

The **xmlns:cd** namespace, specifies that elements with the cd prefix are from the namespace "http://www.recshop.fake/cd#".

The **<rdf:Description>** element contains the description of the resource identified by the **rdf:about** attribute.

The elements: **<cd:artist>, <cd:country>, <cd:company>,** etc. are properties of the resource.

```
<?xml version="1.0"?>

<rdf:RDF
xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
xmlns:cd="http://www.recshop.fake/cd#">

<rdf:Description
rdf:about="http://www.recshop.fake/cd/Empire Burlesque">
  <cd:artist>Bob Dylan</cd:artist>
  <cd:country>USA</cd:country>
  <cd:company>Columbia</cd:company>
  <cd:price>10.90</cd:price>
  <cd:year>1985</cd:year>
</rdf:Description>

<rdf:Description
rdf:about="http://www.recshop.fake/cd/Hide your heart">
  <cd:artist>Bonnie Tyler</cd:artist>
  <cd:country>UK</cd:country>
  <cd:company>CBS Records</cd:company>
  <cd:price>9.90</cd:price>
  <cd:year>1988</cd:year>
</rdf:Description>
.
.
.
</rdf:RDF>
```

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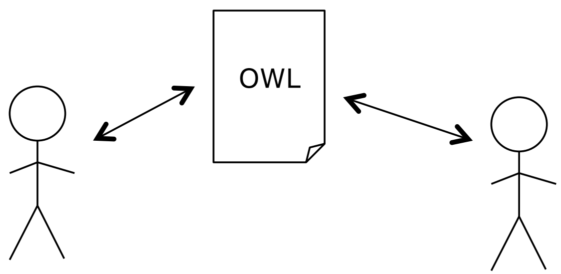
Specification of Terms - OWL

- OWL Ontology Web Language
- Adds even more strucutre to the meta-data definitions

- Adds relation to Objects, so that Logic can be used to Infer facts about the data.



Outline of the Lecture

- Repeating where we are right now
  - Intelligent Agents of various types
  - How to make agents think and plan
- Constraint Satsifaction Problems
  - A variant of planning problems (still in one agent)
- Multi-agent interactions
  - Some concepts for cooperation
- Agent Communication
  - Ontologies, XML, RDF and OWL