Decision-making and path finding

2008-02-05

Contents

- Decision-making system of robots:
  - **Xie, M.** *-- Fundamentals of robotics - linking perception to action*. p. **573-600**
- Path planning: The A* algorithm:
  - **Murphy, R. R.:** *Introduction to AI robotics,* p. **351-365**
    (Copies distributed on the lecture)

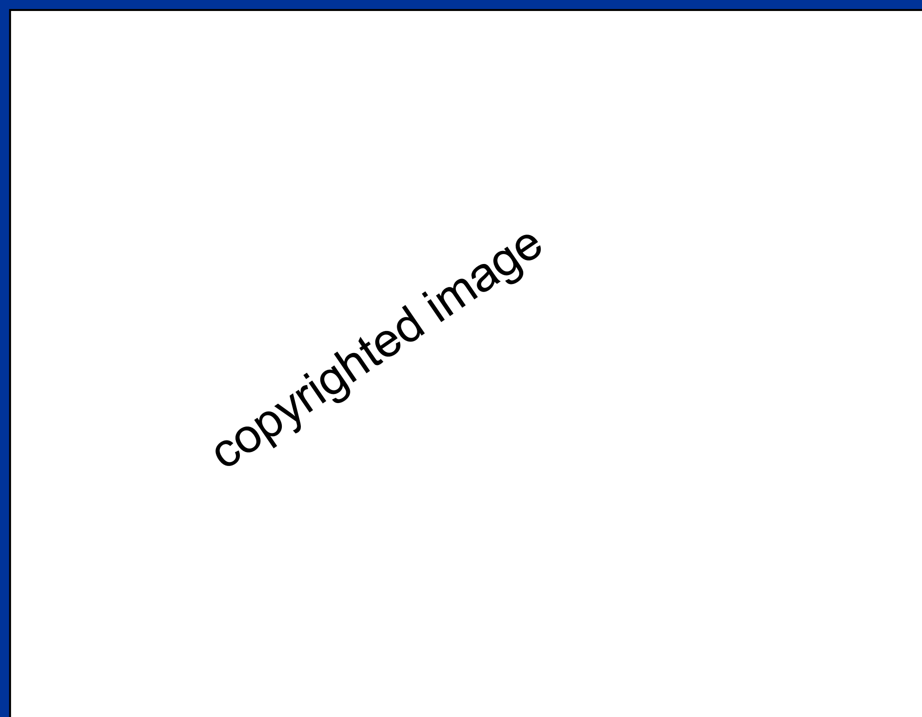
Our ultimate goal:

- Develop **autonomous robots**
  - Intended to move around freely in unstructured and dynamically changing environments, **without** (continuous) human guidance.

- Historically, autonomous robots are closely related to industrial **automation**.

Industrial **Automation:**

- Industrial assembly line in the beginning (Dearborn, Michigan, 1928)



Industrial **Automation:**

- Modern car assembly line

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Industrial **Automation:**

- Automated guided vehicles (AGVs)

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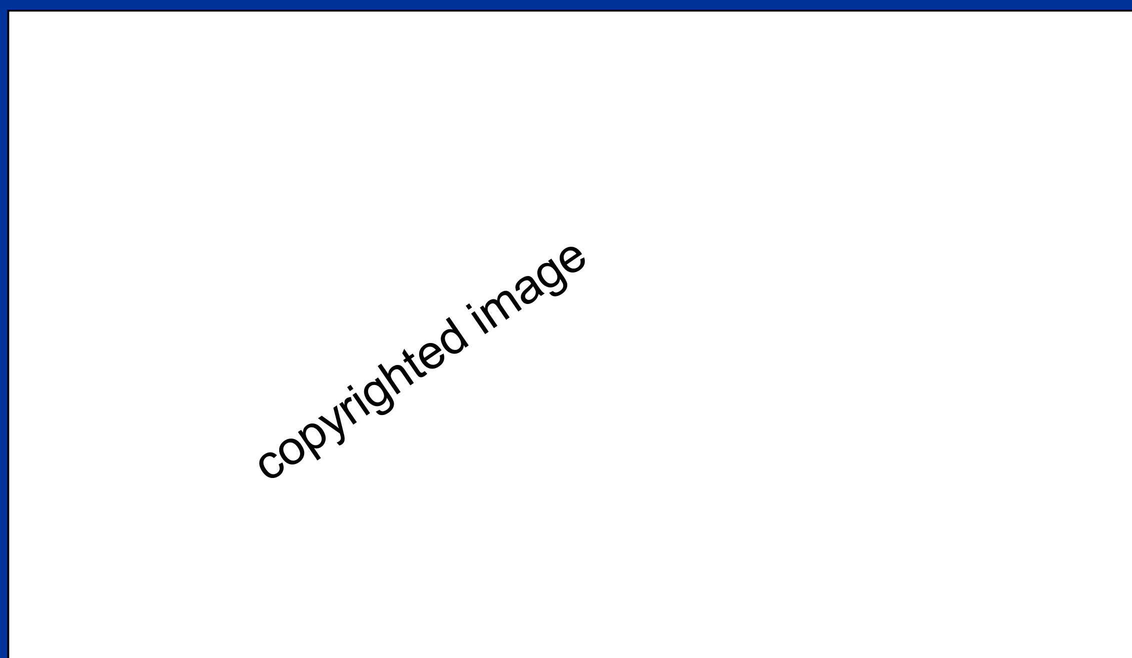
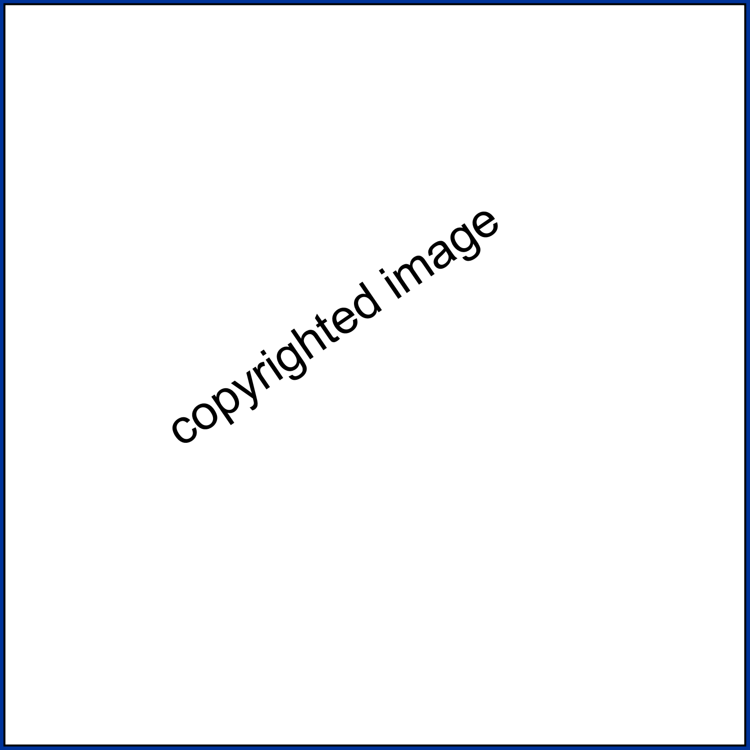
Examples of **Autonomous Robots:**

- Entertainment robots:



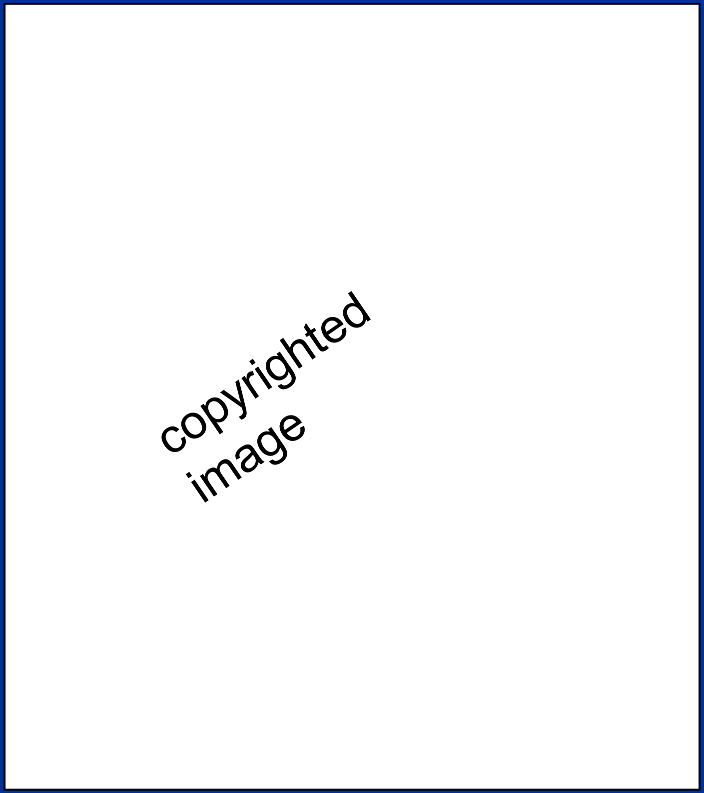
Examples of **Autonomous Robots:**

- Lawn mower robots:



Examples of **Autonomous Robots:**

- Service robots:



Examples of **Autonomous Robots:**

- Planetary exploration robots:

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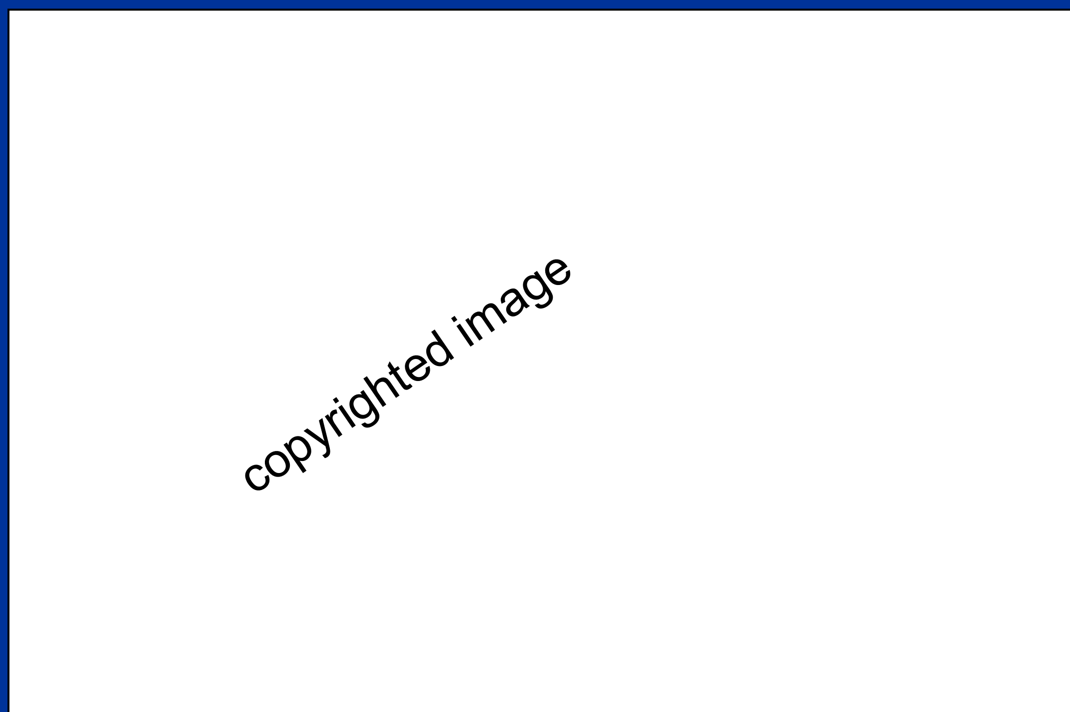
Examples of **Autonomous Robots:**

- Unmanned aerial vehicles (UAVs):

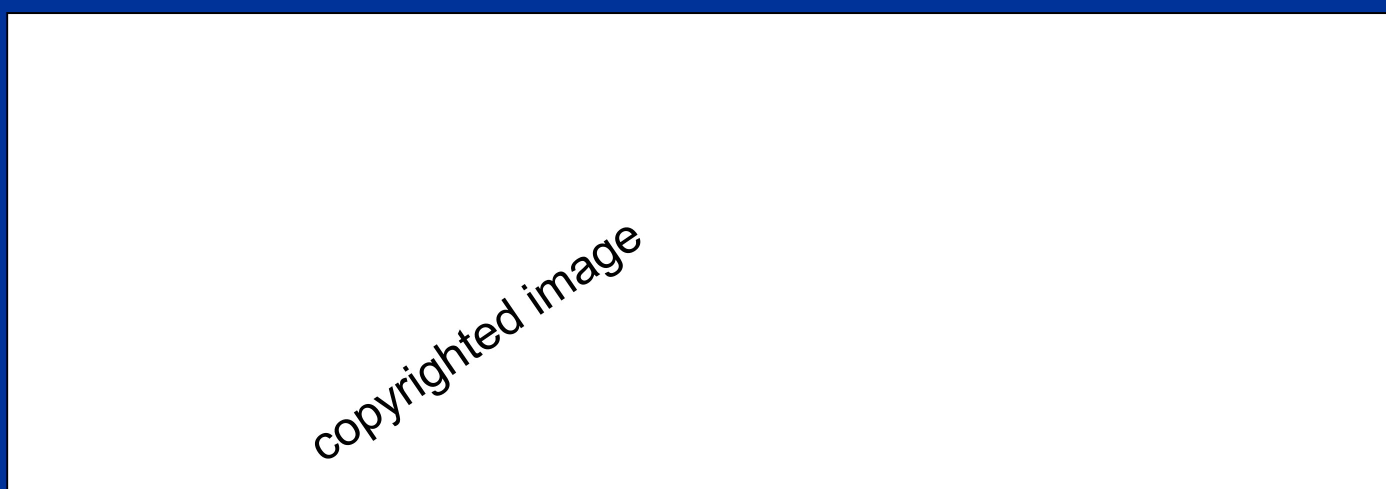


Automation and autonomy

- **Automation** was mainly deployed in industry for better productivity
- **Autonomous robots** are indentended to co-exist in human society for better service
  - Must be sociable and educable
- Clearly, **decision-making** is an indispensable part in both!

Automation

- In **automation**, the desired output of the system must be given in advance (goal state).
- Automated systems requires a **decision-making process** and **automatic feedback loops**:



Automation

- *Definition:* **Automation** is the interaction between a decision-making process and an action-taking system which does not require any human intervention.

Automation vs. Autonomy

- **Automation systems** usually depend on the specification of a the *goal*, usually pre-programmed by human operators.
  - without the specification, an automated system will *not* produce any useful outcome (action).

- An **autonomous system** is an automated system which has gained the ability to *self-specify* the desired outcome, or *goal*.

System categories

- **Active system:**
  - acts on its own, no feedback
- **Reactive system:**
  - respond to outside stimulus
- **Automated system:**
  - contained with a decision-making mechanism
- **Autonomous system:**
  - specifies its own desired output, or *goal*
- **Intelligent system:**
  - ability to achieve predefined outcome in different ways, subject to its own decisions

Levels of autonomy:

- **Goal** level:
  - Human intervention, or self-specify
- **Task** level:
  - goal decomposed into sequence of ordered tasks
- **Action** level:
  - task -> sequence of ordered actions
- **Motion** level:
  - action -> sequence of ordered motions, controlled by feedback loop

A decision-making process

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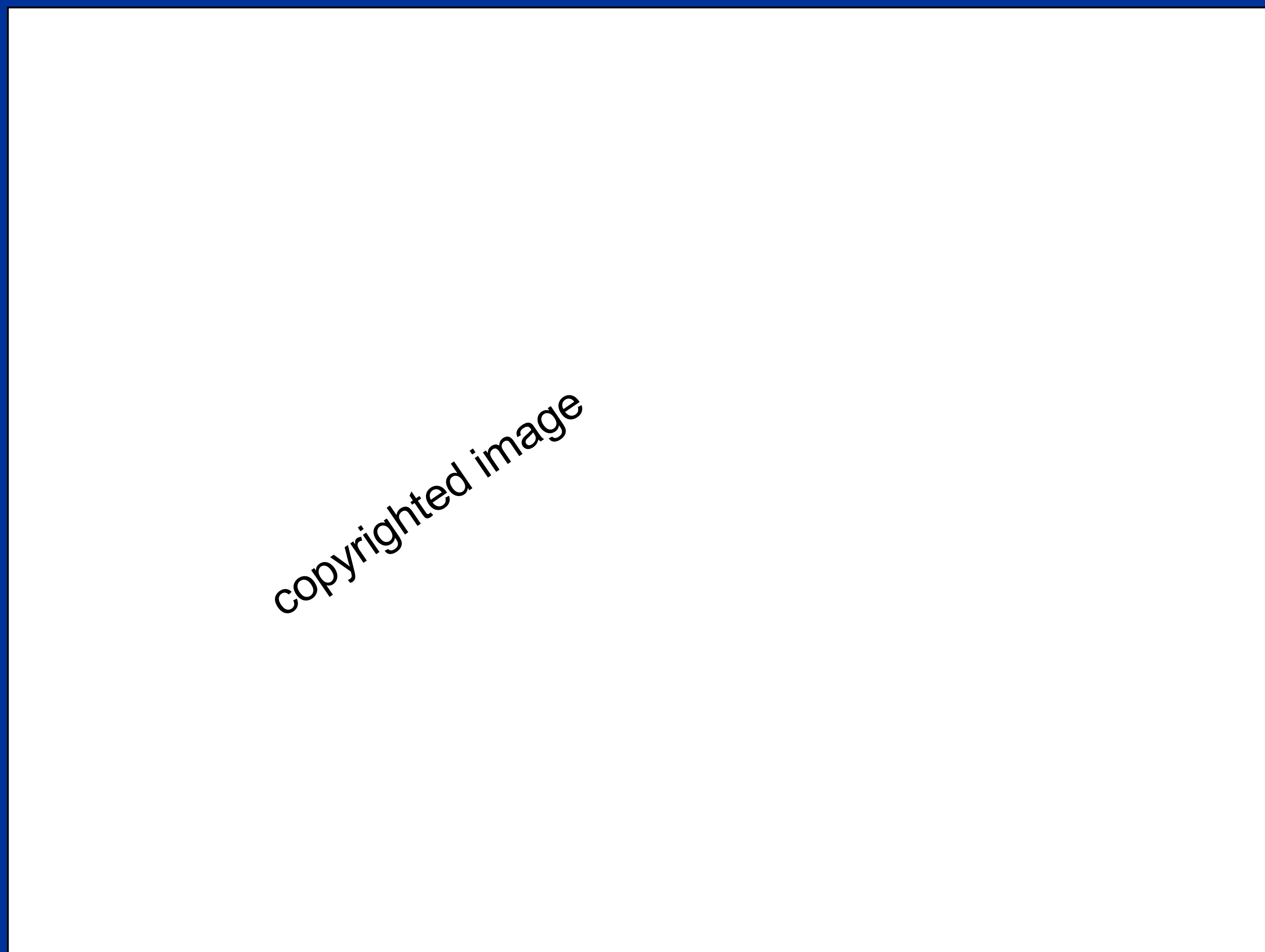
Difficulties and Methods



Uncertainty

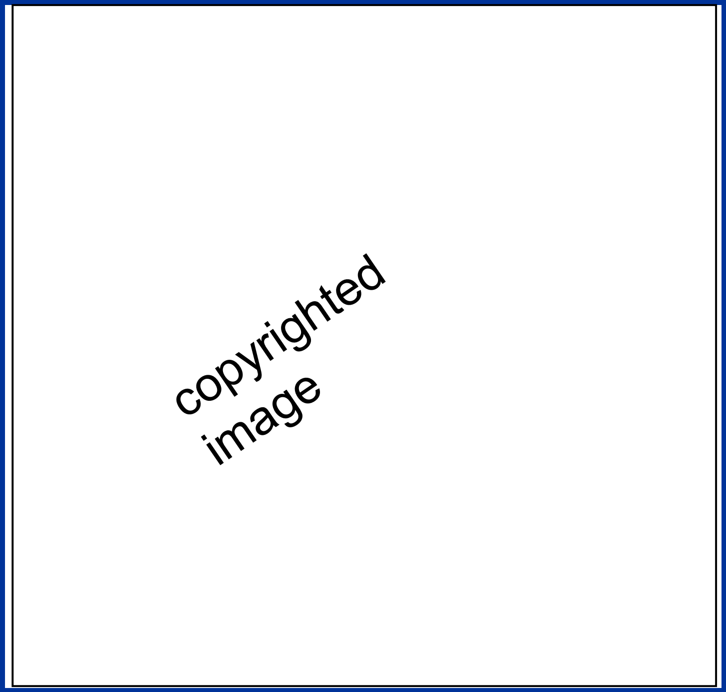
- **Imprecision** in sensory data:
  - Measurement stability, noise, hysteresis, etc.
- **Incompleteness** in sensory data**:**
  - Limited sensor range
- **Ambiguity** in the output:
  - Arise due to *fuzziness* in goal specification.

Redundancy

- **Multiple sources** of input:
  - The same physical quantity measured by different sensors (or same sensors, but different signal processing techniques).
- **Multiple mappings**
  - Ex. kinematically redundant robot arm
- **Semantic overlapping**
  - Goal specification have overlapping terms.

EX. redundant robot arm

- *Infinite* number of solutions!



- However, redundancy can be used advantageously!
  - Sensor fusion

Methodologies in Decision-making

- **Deliberative planning** (Classical AI, "top-down"):
  - Expert knowledge
  - Statistical inference
  - Fuzzy inference
- **Biologically inspired framework** ("bottom-up"):
  - Artificial neural networks (ANNs)
  - Evolutionary robotics (ER)
  - Behavior-based robotics (BBR)

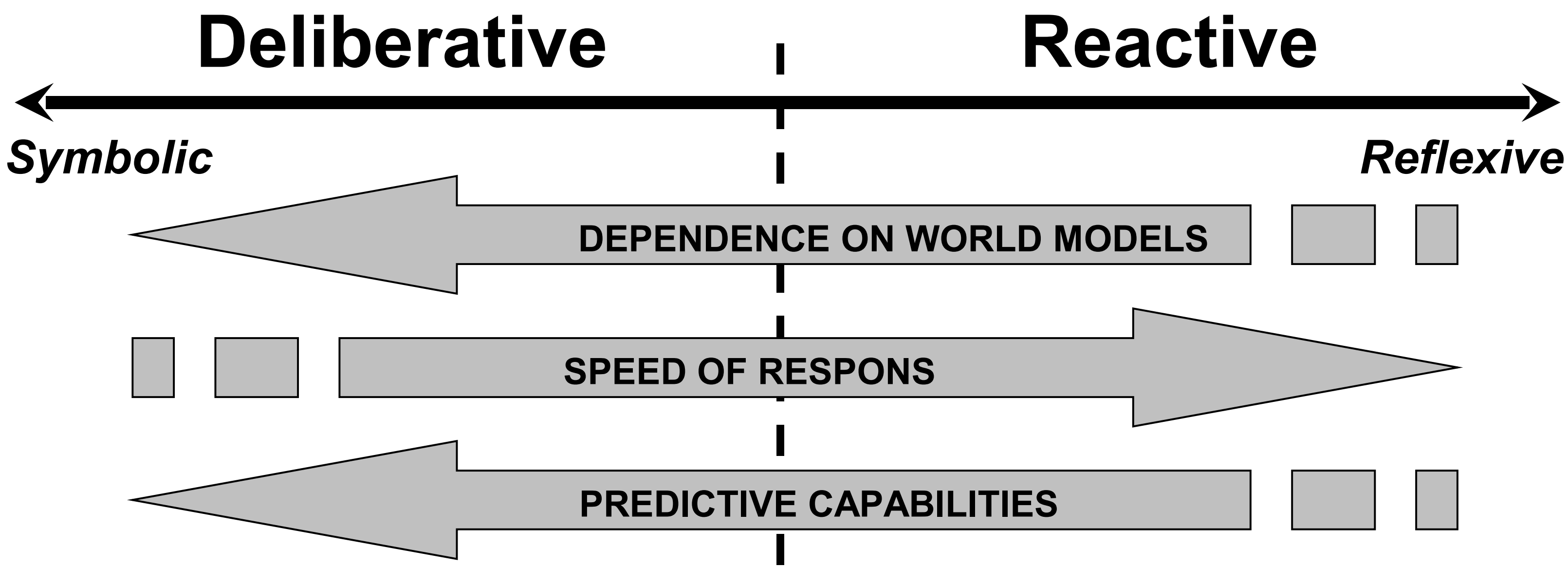
Why bio-inspired methods?

- Autonomous robots are inspired by the properties of a biological creatures.

  => Biologically inspired control is logical.

- Alternative methods have serious drawbacks:
  - Bio-inspired methods *do not* require accurate models, or reference trajectories for execution

Spectrum of Decision-making systems



Accurate (symbolic) world models
Slower response
Reasoning
High-level intelligence (cognitive)

No world model is required
Realtime response
Simple computation
Low-level intelligence

After Arkin

Hybrid methods

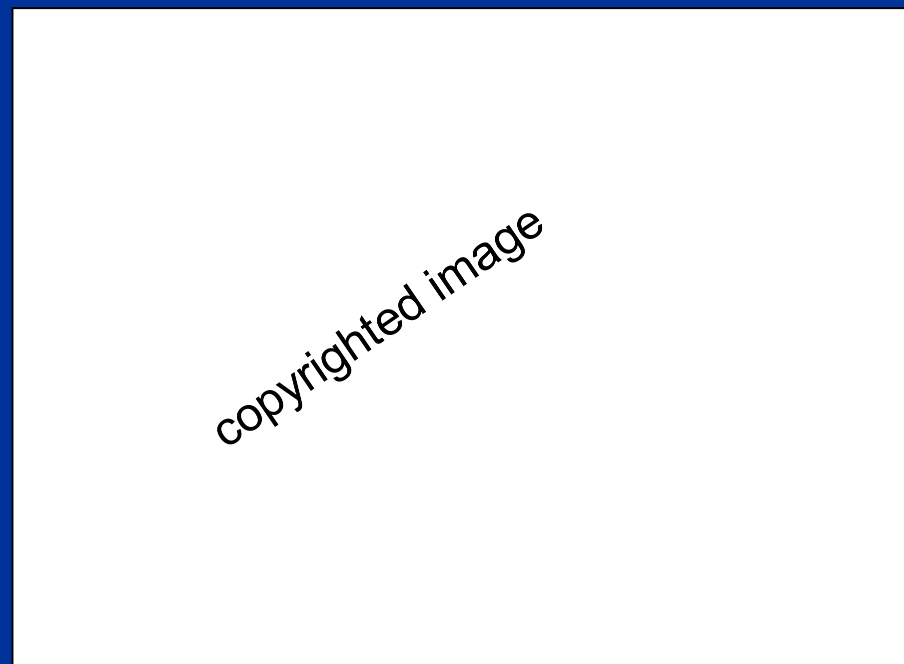
- Union of **deliberative** and **BBR** methods
- *A priori* world knowledge needed in order to unleash the full potential of BBR:
  - Reasoning over world models permits *reconfiguration* of reactive control system
- Biological evidence of hybrid systems:
  - Deliberative processes and involuntary, "automatic" behaviors are integrated in e.g. humans

Path planning and navigation

- **Objective**: Determine a *path* to a specific *location*.
- Two main approaches:
- **Topological** path planning
  - *Qualitative* navigation
  - Based on **Landmarks** and **Gateways**
- **Metric** path planning
  - *Quantitative* navigation
  - Produces an *optimal* route

Metric path planning

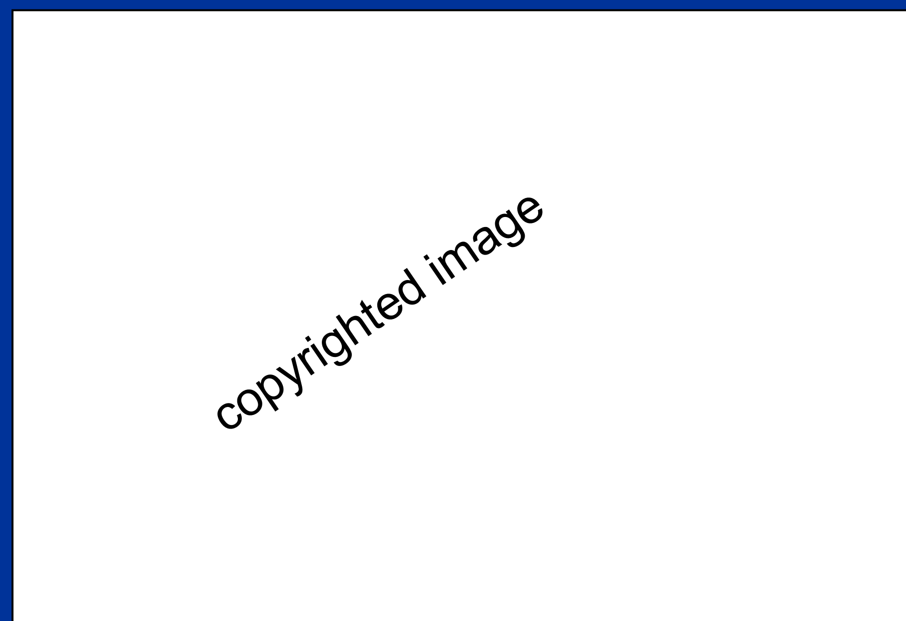
- **Objective**: Determine a *path* to a specific *location* =>
  Requires a **map**:



- Map-making will be studied later in the course

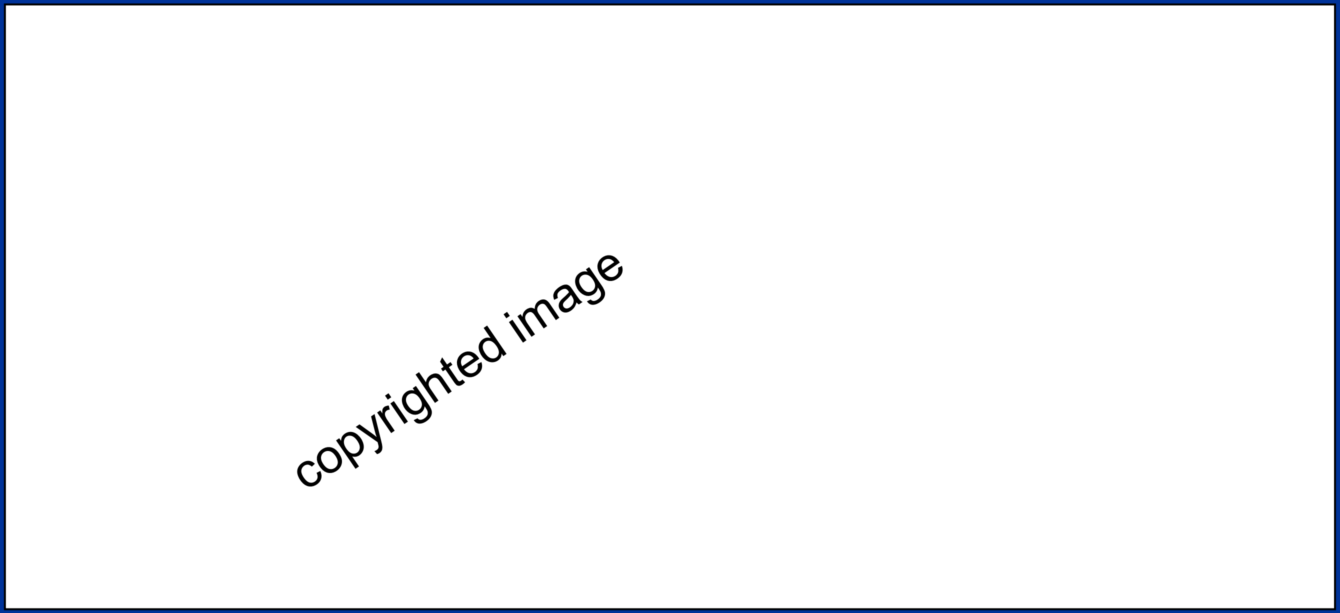
Regular grid

- A 2D Cartesian grid projected onto the world space =>
  Our data structure, or *representation*
- **Occupancy grid:**
  - States:
    unknown,
    free,
    occupied



Connectivity

- Each cell is considered a *node* => connected *graph*



- *4-connected* grid, or *8-connected grid*

Issues with grids

- *Digitization bias*

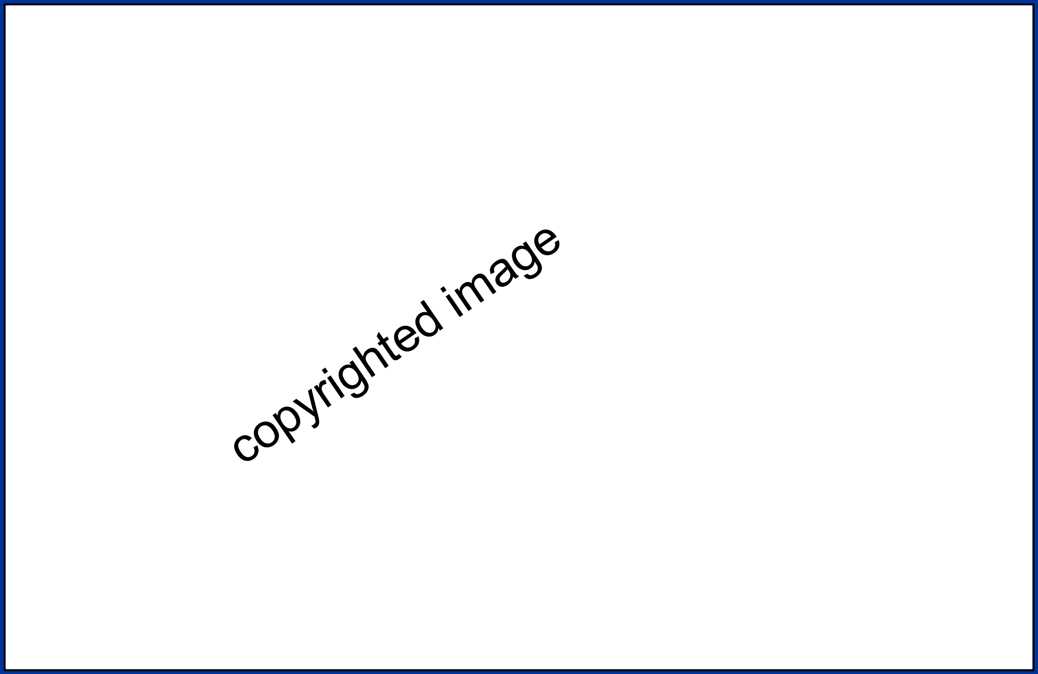
  => wasted space

- Increase the resolution

  => High storage cost, high number of nodes to visit for the algorithm

- Or use quadtrees...

Quadtrees



- Recursive grid:
  - divide each cell into four sub-elements

A* search algorithm

- Classic graph search algorithm
  - Based on the "A search" method
- Goal is to find the optimal path (according to some measure of "best")
- Guaranteed to find the optimal path!
  - see e.g. Russel & Norvig: *Artificial Intelligence, A modern approach*

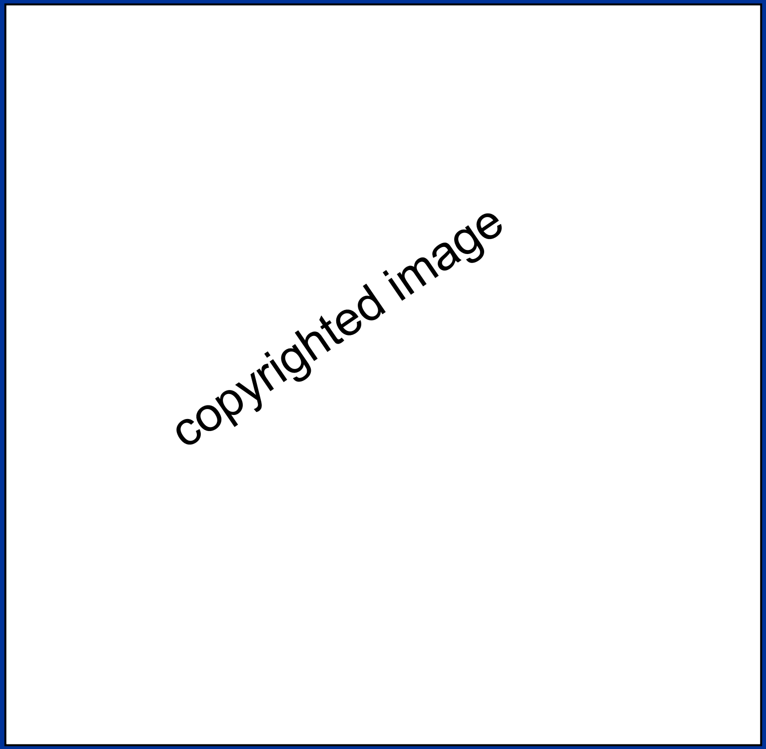
Example: A search

- Evaluation fuction:

  $f(n) = g(n)+h(n)$

  $g(n)$ = cost of getting to node n

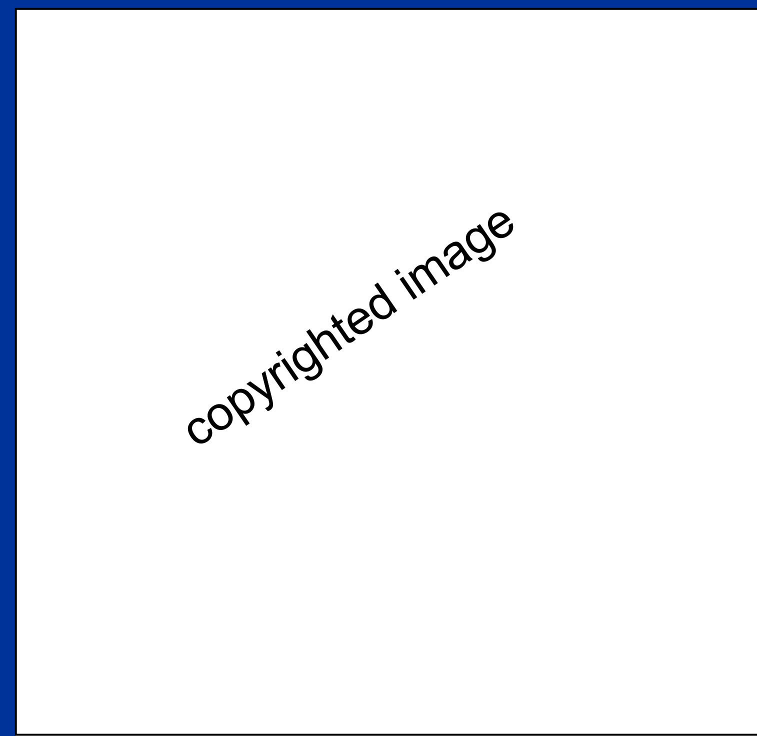
  $h(n)$ = cheapest cost of getting from n to goal



- Incrementally generates the optimal path

Example: A search

- Start at A, then move to B or C?
- *f(B) = g(B) + h(B) =* =1+2.24 =3.24
- *f(C) = g(C) + h(C)=* =1+1=2.0
- *f(C) < f(B):* go from A to C (prune off B)

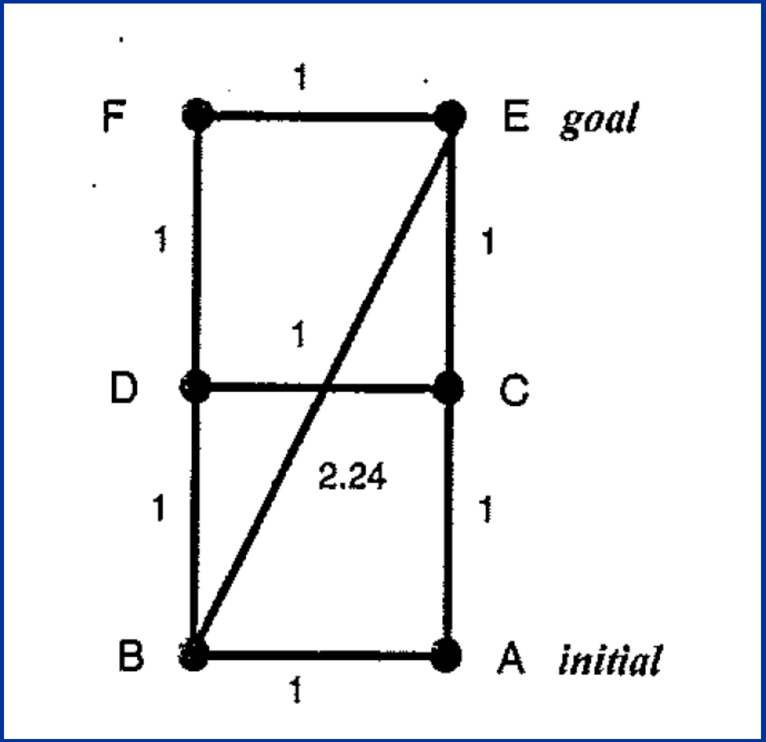


Example: A search

- If *h(n)* is NOT known at every node =>

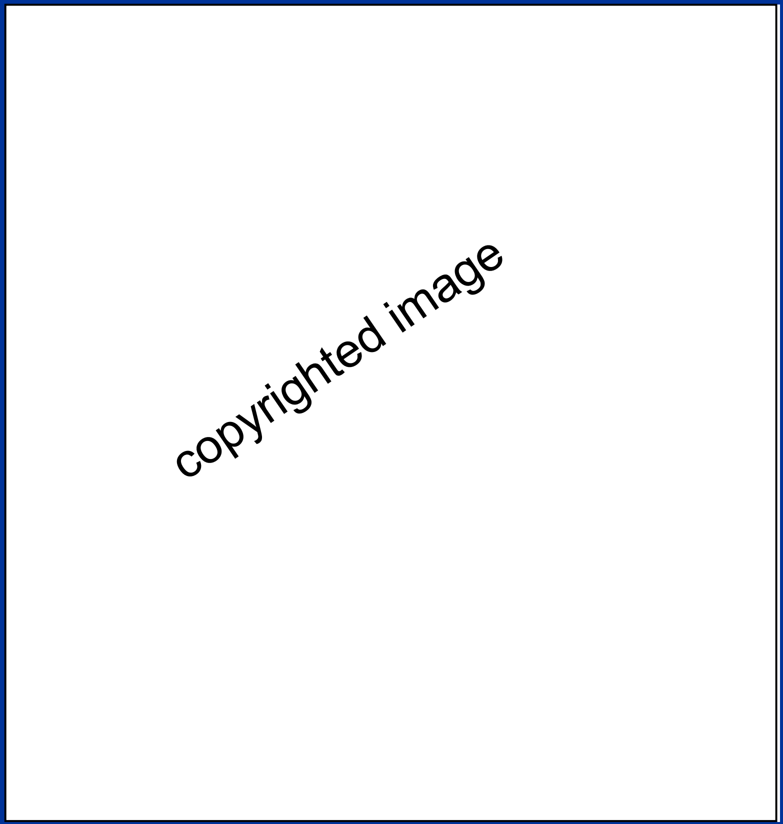
  algorithm needs to visit all the nodes!

- A* reduces the number of *possible paths*



Example: A* search

- A* makes an *estimate* of *h(n)* => poor paths can be pruned off

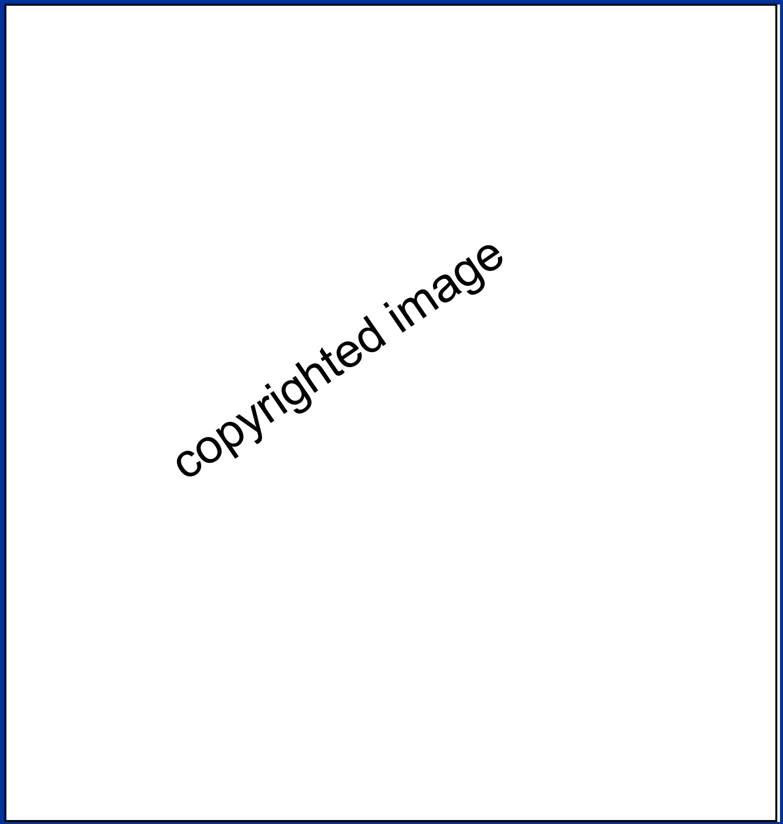


- Evaluation function: $f^*(n) = g^*(n)+h^*(n)$
- $g^*(n) = g(n)$
- $h^*(n) \leq h(n)$ **admissibility condition**

Example: A* search

- Heuristics for *h*(n):*
  The *Euklidian distance*

- *Locations* of each node is known =>
  distances between two nodes can be calculated



Example: A* search

- Consider node A:

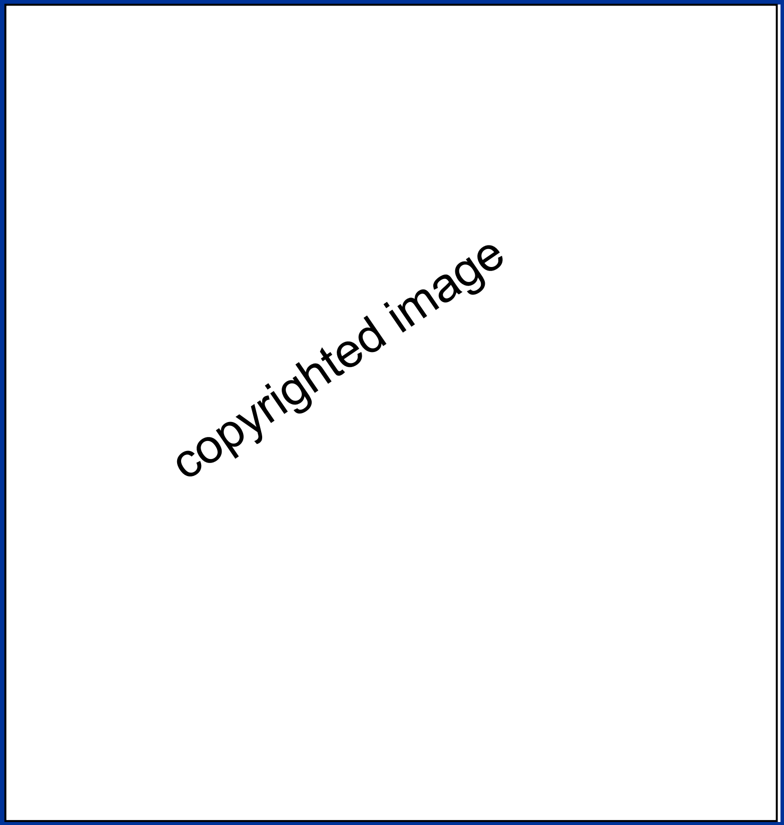
  $f^*(B) = 1 + 2.24 = 3.24$

  $f^*(D) = 1.4 + 1.4 = 2.8$

- Next, consider node D:

  $f^*(E) = 2.8 + 0.0 = 2.8$

  $f^*(F) = 2.4 + 1.0 = 3.4$



- Then, select path A - D - E

A* search limitations

- Can be used with any *graph-based* representation
- Considers only the *distance cost* between nodes

A* search demo programs:

- Pathfinder A Star:
  - http://herbert.gandraxa.com/herbert/pfa.asp
- A* Explorer:
  - http://www.generation5.org/content/2002/ase.asp