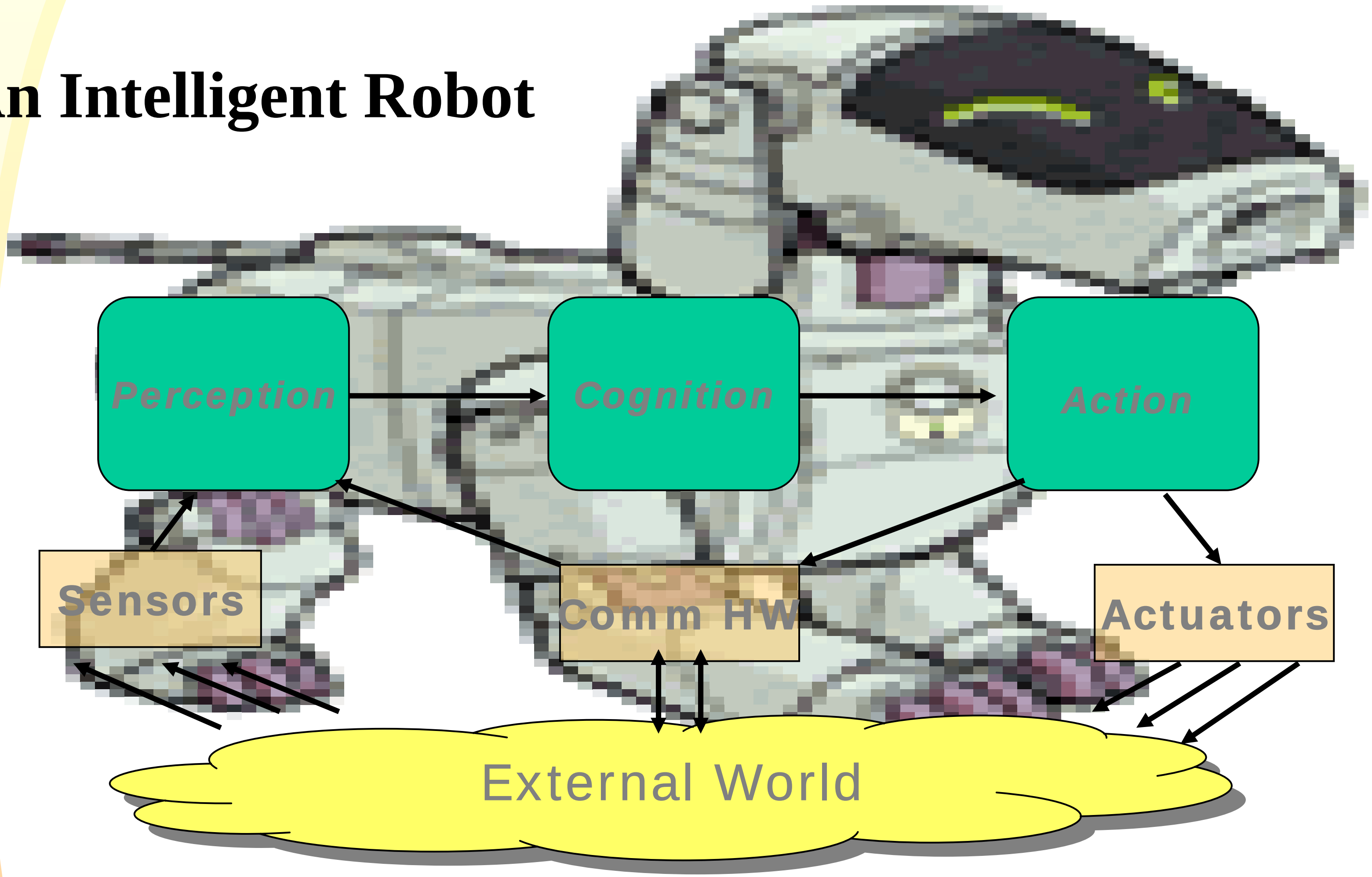
Multi-Robot Systems

Universiteit Utrecht

An Intelligent Robot



AIBO Programming

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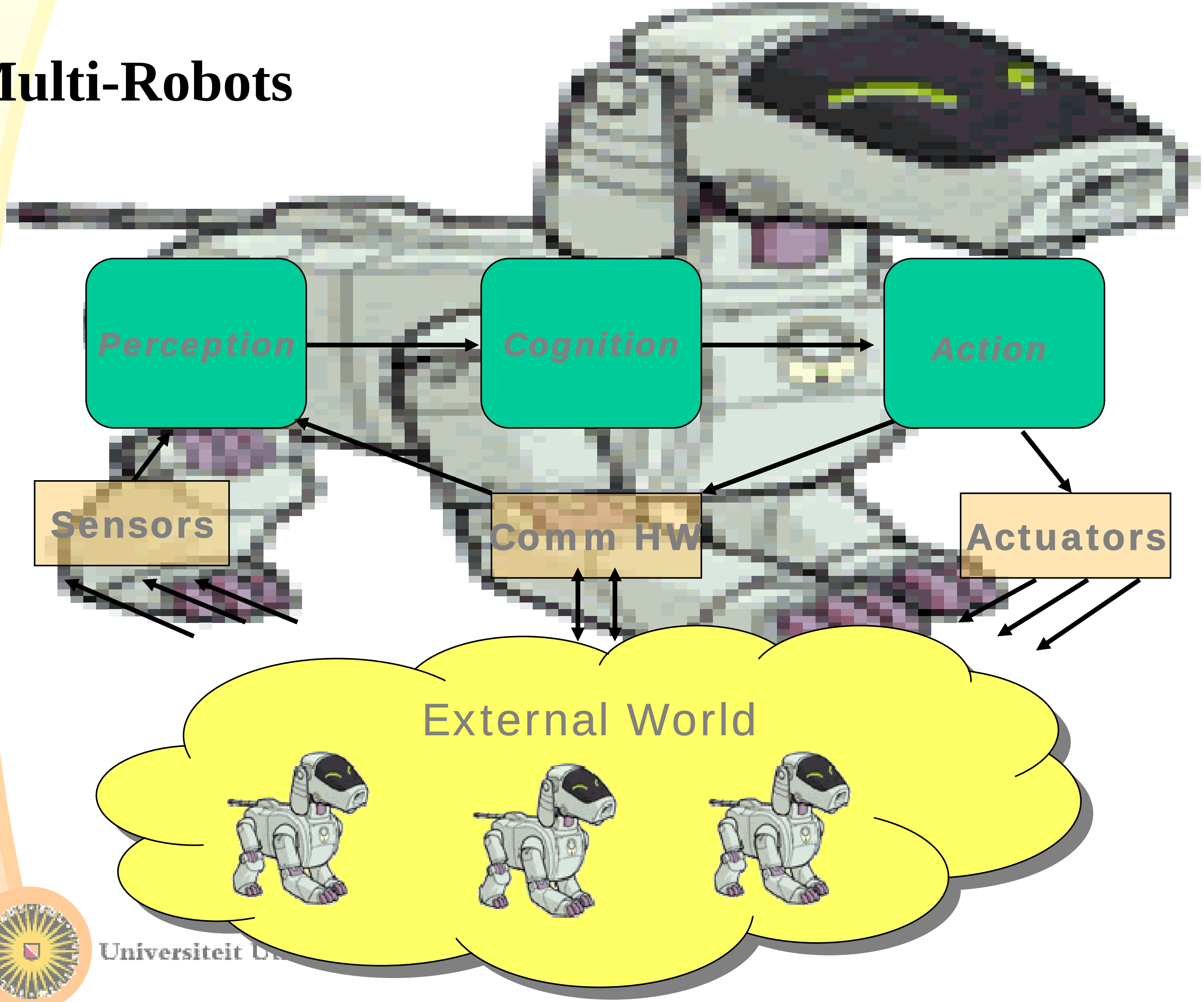
Multi-Robots



What changes?

1. Coordination
   - Traffic, games, …
2. Cooperation
   - Class, shopping,…
3. Teamwork
   - AIBO programming groups?

Coordination in space

- Spatial group behaviors
  - Foraging, grazing, sweeping, …
- Basic Behaviors (Mataric)
- Coverage (Gage, and many others since)
- Social potential fields (Balch)

Example spatial behaviors

- Foraging
  - Robots go out, collect items, bring them back
  - Found in bees, ants, other species
- Flocking
  - Robots move around while clustered, no single leader
  - Fish, herd animals, birds

Additional spatial behaviors

- Formations
  - Robots move while maintaining relative positions
  - Military movement (both on ground and in air), birds
- Coverage
  - Blanket
  - Sweep
  - Barrier

Coverage tasks

Task	Type of coverage
Mine deployment	barrier
Reconnaissance	sweep
Demining	sweep
Vaccum cleaning	sweep
Guard	barrier
Communications relay	blanket

Generating spatial behaviors

Combine simple behaviors to create complex behaviors

- Identify set of distinct atomic behaviors
  - Program them using whatever means
- Combine output to create complex behaviors
- Brooks…?

Basic Social Behaviors

- Safe-wandering: Move around without bumping
- Following: follow another robot
- Dispersion: move away from other robots
  - Maintain distance within some minimum
- Aggregation: move towards other robots
  - Maintain distance within a maximum
- Homing: move towards specific goal location

Implementing safe wandering

- Avoid obstacles:
  - If obstacle on one side
    - Turn away from obstacles
    - If turned 3 times in a row, back up and turn randomly
  - Else
    - Stop, wait
    - If continues, back up and turn randomly
- Avoid Kin: (distinct, to exploit symmetries)
  - Turn away from another robot
- Move forward D_FORWARD, turn randomly

Additional basic behaviors

- Following:
  - Whenever another robot within D_FOLLOW
  - Turn towards robot (NOT away)

- Dispersion:
  - If one or more robots within D_DISPERSE
  - Move away from their centroid

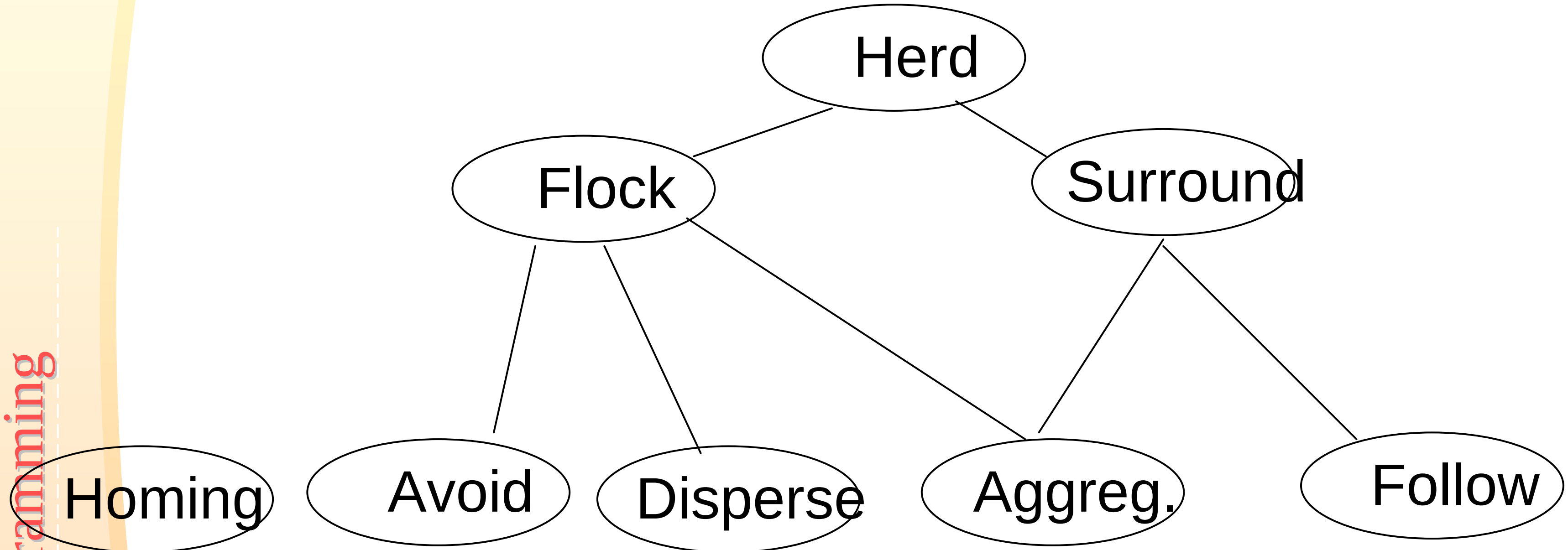
Additional basic behaviors

- Aggregation:
  - Whenever one or more robots outside D_AGGREGATE
  - Turn towards their centroid
  - Otherwise stop

- Homing:
  - If at home location, stop
  - Otherwise turn towards home location, move forward

Combining complementary behaviors

- Behaviors are combined in parallel



Flocking algorithm

- Weighted sum: avoid, disperse, aggregate, and home
- Set conditions such that no interference occurs:
  - D_AVOID < D_DISPERSE < D_AGGREGATE
- Stable, robust to mechanical crashes of robots
  - Also to obstacles

Combining contradictory behaviors

- If behaviors contradict, combine them over time
  - *Temporal sequencing*

<u>Foraging:</u>

```
1.  If crowded?  disperse
2.  If at-home?
3.      if have-puck?  Drop-puck
4.      else disperse
5.  If sense-puck?
6.      if not have-puck? Pickup-puck, home
7.  If behind-kin?  Follow
8.  If behind-non-kin?  Avoid
```

Discussion

- Not all basic behaviors are social
  - For instance, homing
- Small changes are still required to basic behaviors
  - In flocking, had to change aggregate so leader does not turn
- Very hard to fine-tune parameters (sounds familiar?)
- No known set of behaviors to cover a domain
- No way to decompose a wanted complex pattern into basic behaviors
- Relies on recognizing kin (through comm. in this case)

Blanket Coverage of area

- Alternative 1: With no communications
  - A potential fields approach
  - Good dispersion is not guaranteed
- Alternative 2: With communications
  - Incremental heuristic greedy search
  - Robot role assignment and re-assignment

Sensor Networks

- Collection of sensors spread over an area of interest
- Each sensor node has:
  - Sensing (of environment), Computation, Locomotion
  - Communications (to operator)
  - Communications and/or sensing (other nodes)
- Applications:
  - Cellular phones and communication relays
  - Radar tracking, acoustic sensors
  - Chemical/bio-hazard disaster management

Self-deployment

- We want network to efficiently cover an area
  - Blanket coverage (Gage 1992)
- Ideally, sensors autonomously decide position
  - May change position to respond to changes
- Position Considerations:
  - Occlusion
  - Direction of sensing
  - Maintaining communications to operator
  - Maintaining other nodes within range

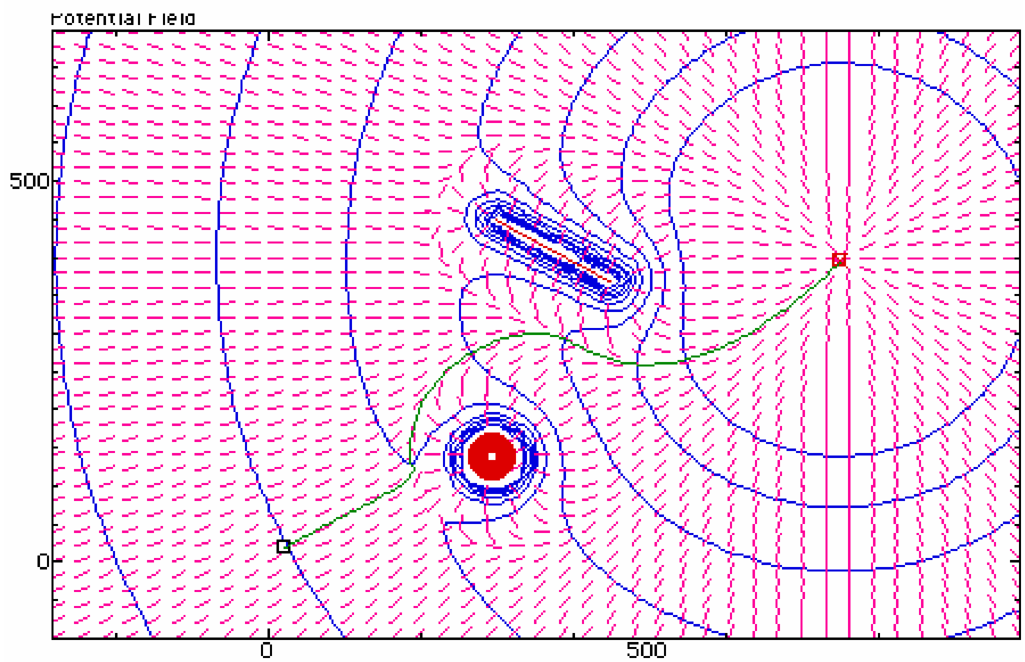
A potential fields approach

Use repealing potential fields to avoid other nodes

- All nodes start in some initial place, close together
- Each node moves away from other nodes
- Each node moves away from obstacles
- This results in a dispersion process

Potential Fields

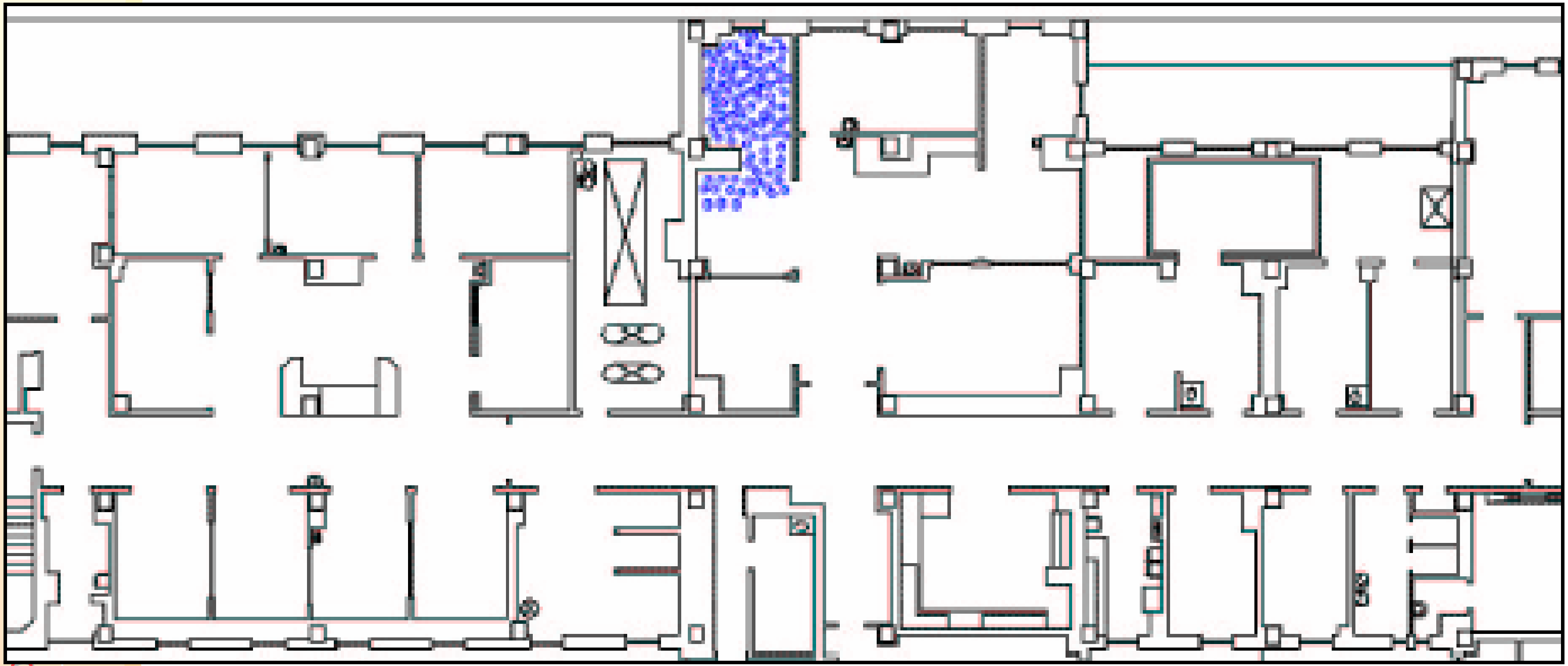
- Potential fields: Artificial repulsion field around obstacles plus attraction field around the goal.



Dispersion (and its termination)

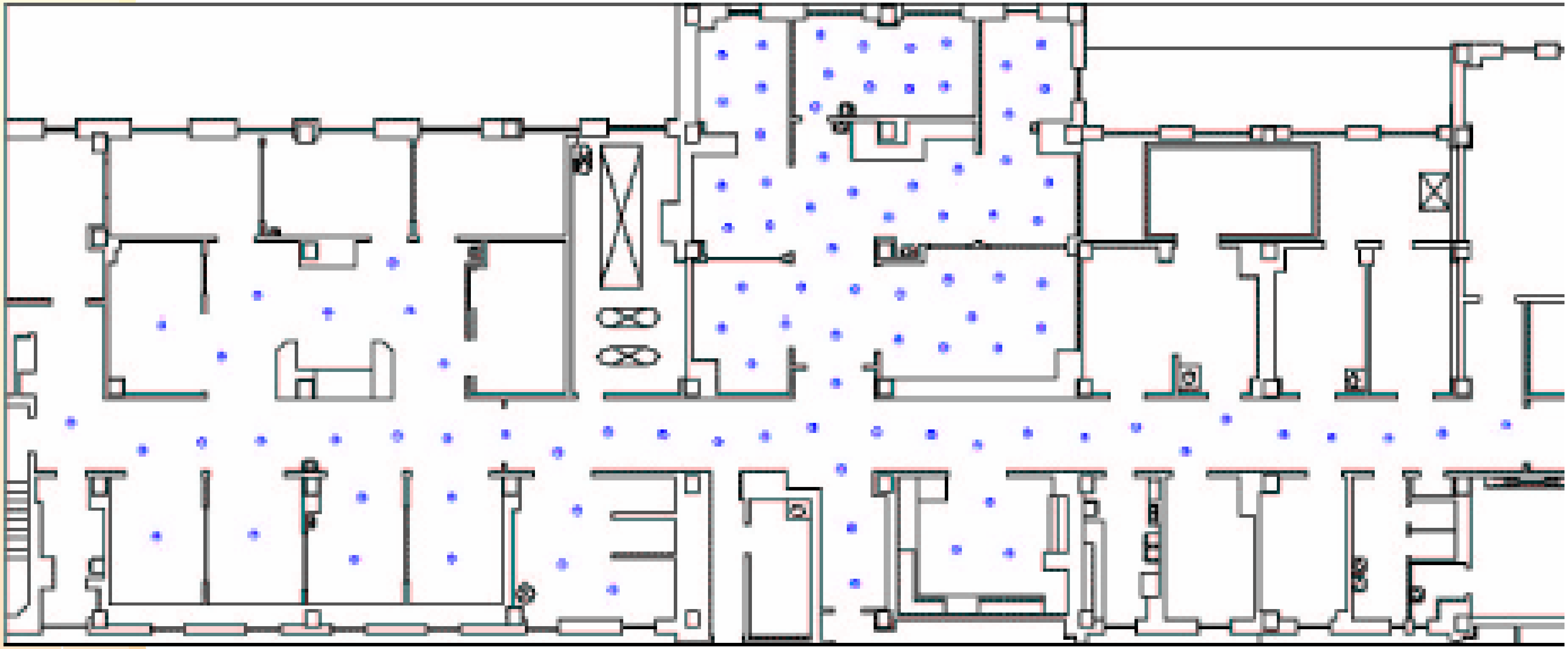
- Applying these forces cause robots to move away
  - From walls, obstacles
  - From other robots
- But then they may never stop
- Solution: Add a friction force
  - Cancels slow movement and keeps robots in place
  - As long as no change in environment

Example



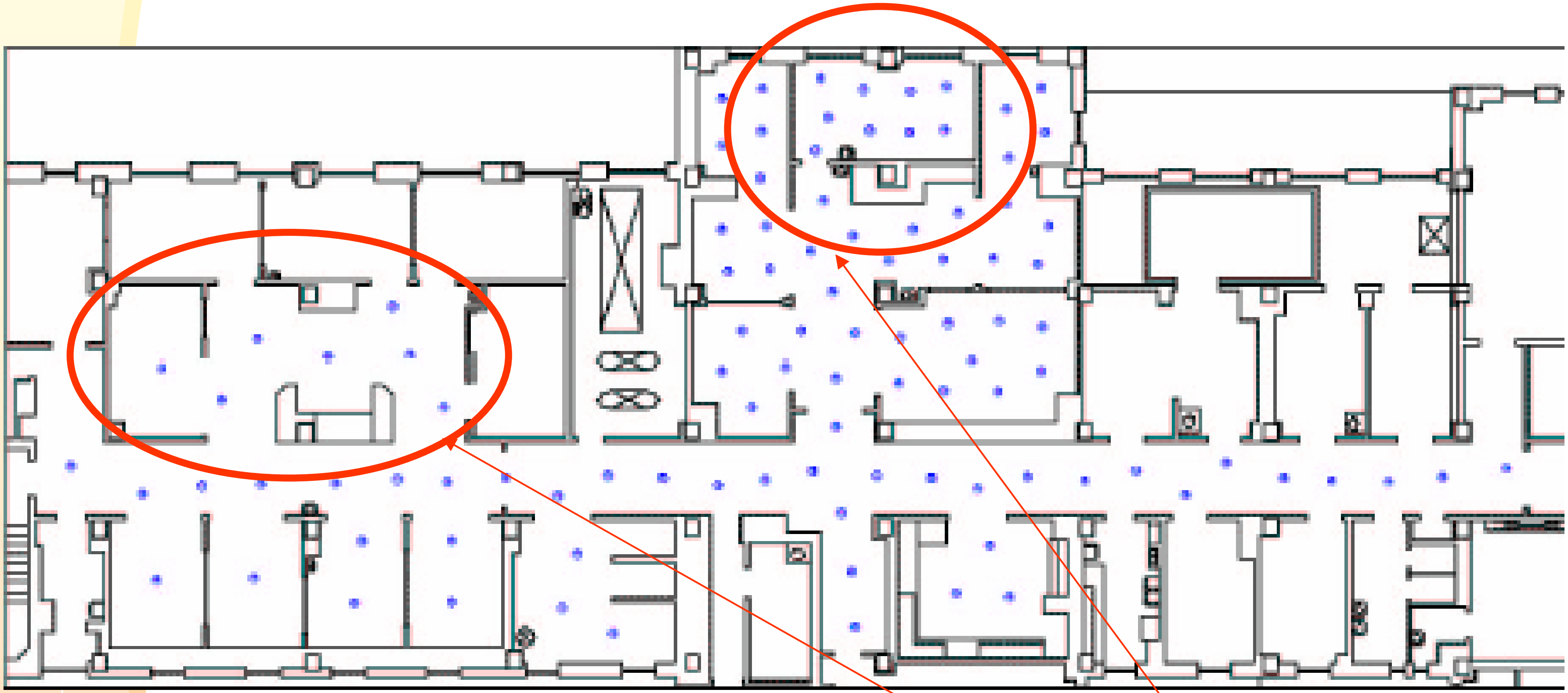
Initial Configuration

Example



Final configuration

Problem: Sub-optimal coverage



Compare coverage density here, and here.

Additional issues

- Sub-optimal coverage may occur
  - Dispersion is not really even
  - Nodes could have been used better
- Contact between nodes may be lost
- Assumption of omni-directional sensing, locomotion
- Scalable, simple to implement

A heuristic deliberative approach

- A response to difficulties with potential-fields
  - Same group of researchers
- A deliberative approach
- Decision on position reasons about max. coverage
- Must maintain line-of-sight with each other
  - Unlike full dispersion

Incremental, greedy

1. Insert node
2. Get information about what it senses of environment
3. Use this to estimate best position for next node
   - Heuristic 1: Max range from current
   - Heuristic 2: Max new space sensed
4. Find path, assign node for new position
5. Go back to step 1.

Insert and sense

- We insert a node into a given location
- Sense all around it, and all around other nodes
- Merge all information to form common map
  - Build *probabilistic occupancy* grid
  - From it, configuration space grid, reachability grid

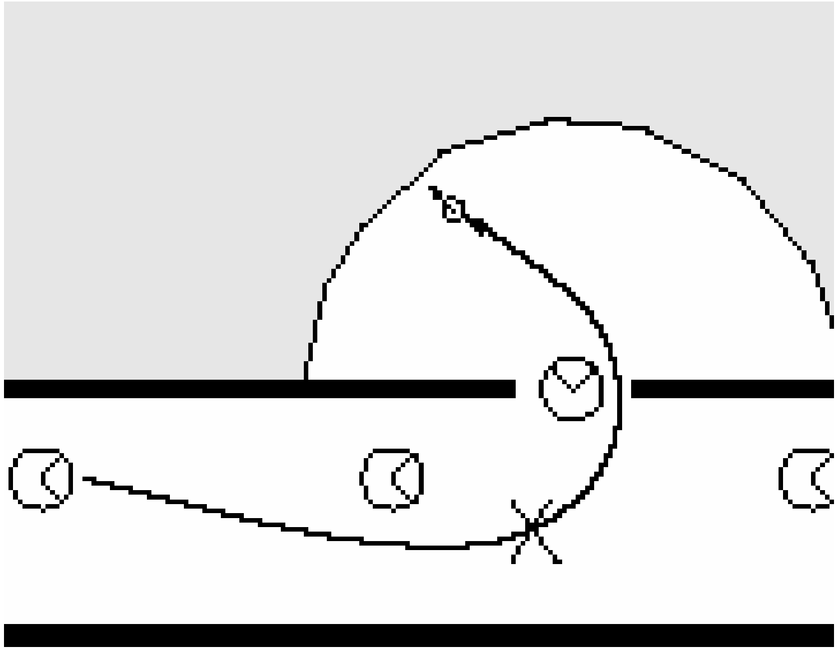
Best new position: Heuristics

- Boundary heuristic:
  - Puts robots in boundary between reachable/unreachable

- Coverage heuristic:
  - Cover greatest area currently unknown
  - All unknown assumed to be free (optimistic)

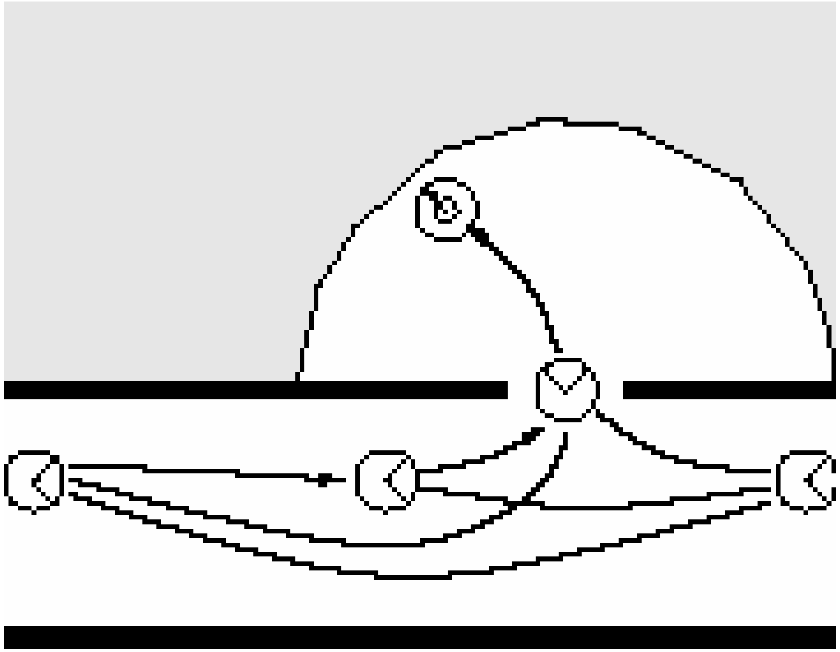
Find path, assign node

- Ideally, just teleport new node into chosen position
- However, in practice it may be blocked by others



Role Re-assignment

- We can instead send a different node to new place
- Re-assign its role to the new node
  - And repeatedly, until no problem in moving



Role reassignment computation

- Construct node reachability graph
  - Which node can reach which
  - Weighted, non-directed: Distance
  - Goal position: dummy goal node
- Shortest path from new node to goal node
  - Using Dijkstra's algorithm
- Move every node on path one-up

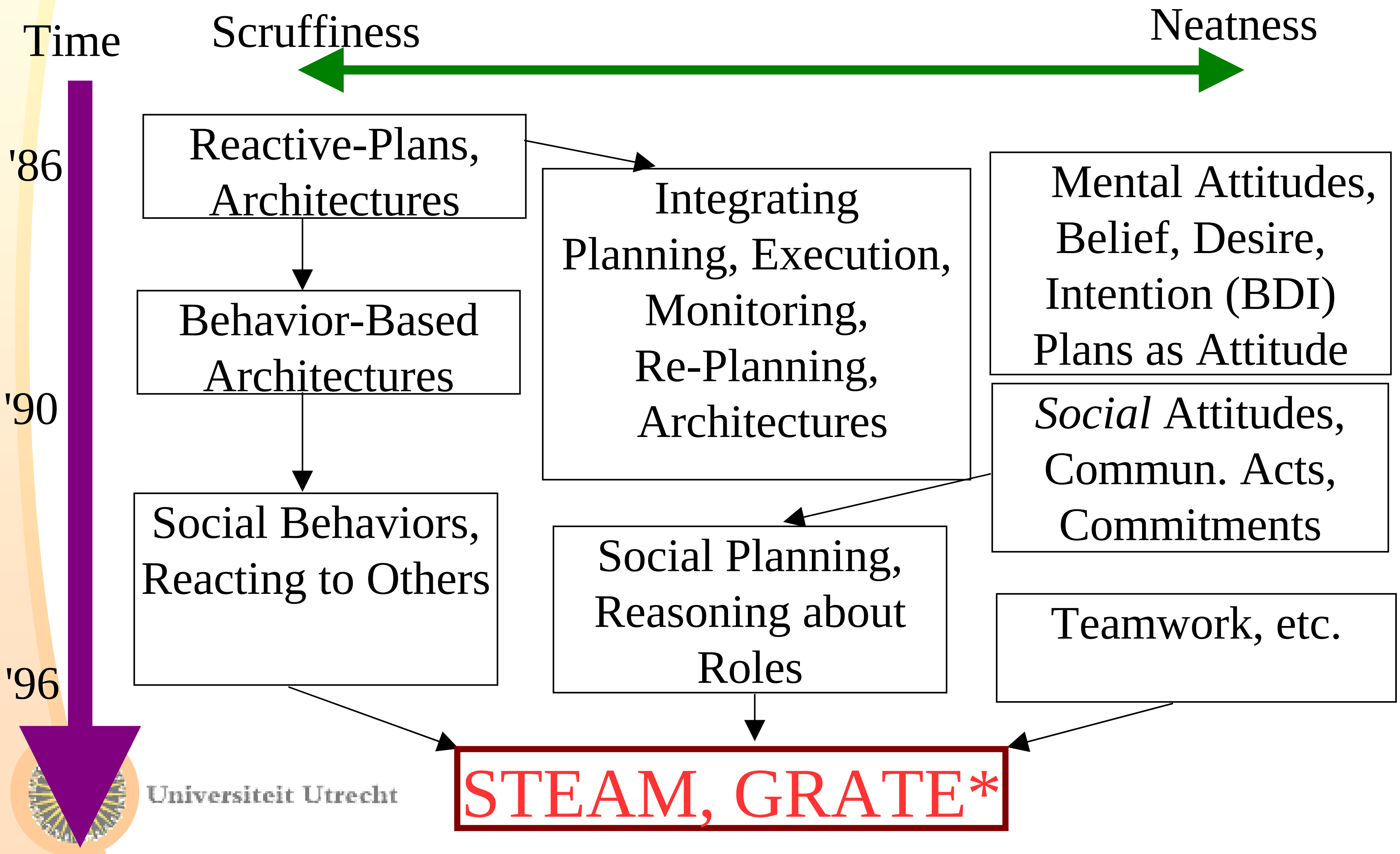
This avoids any obstructions or occlusions.

But may do lots of redundant work.

Teamwork

- Beyond spatial coordination
- What is extra?
  - Mental attitudes
  - Interpretation of actions
- Communication?

A Historical Perspective on Teamwork: From a Single Agent to Multiple Agents



AIBO Programming

What’s Teamwork?

What's Teamwork?

The Famous Convoy Example:

- Two agents Alice and Bob
  - Bob does not know how to get home
  - Bob knows Alice knows how to get home
  - Bob knows Alice lives near Bob
- We have two agents, with matching goals
  - Both want to get to (approximately) same place

- If Bob follows Alice, is that teamwork?

Convoy Example Cont'd

- Imagine Bob following Alice

- Case 1: No teamwork
  - Bob follows Alice without talking to her first
- Case 2: Teamwork
  - Bob asked Alice to lead him home and her agreeing

Case 1: No teamwork

- What happens if Alice goes home as planned?
- What happens if Bob’s car breaks down?
- What happens if Alice decides to change her mind?

Case 2: Teamwork

- Cars are in a convoy (a team)

- If Bob stops, Alice should stop or …
- Alice should use lots of signals
- Alice drives slowly, looks in mirror a lot
- ….

Joint Intentions Key Ideas

- Mutual belief (MB) in the joint intention
  - Mutual in goal
- Joint execution until MB in goal termination
  - Cannot abandon teamwork when privately believe its over
- Termination:
  - Goal achieved
  - Goal unachievable
  - Goal irrelevant

Intuition and example

Team-members work towards the joint goal

- If they privately believe it should be terminated
  - achieved/unachievable/irrelevant
- Then they are responsible for their belief mutual

Consider:

- If Bob decides got home, no need to follow Alice
- If Alice changes her mind about where to go
- If Bob's car breaks down
- …

Additional Theoretical Thoughts

- Teamwork is not coordination:
  - Convoy looks just like traffic when everything OK
  - Chess is coordinated, but not teamwork
  - Tracking involves one-sided coordination, for example
- Teamwork is not necessarily rational
  - May not be rational to “waste” cycles on informing others
  - There is only little work addressing this problem