Behaviour-Based Control

IAR Lecture 5

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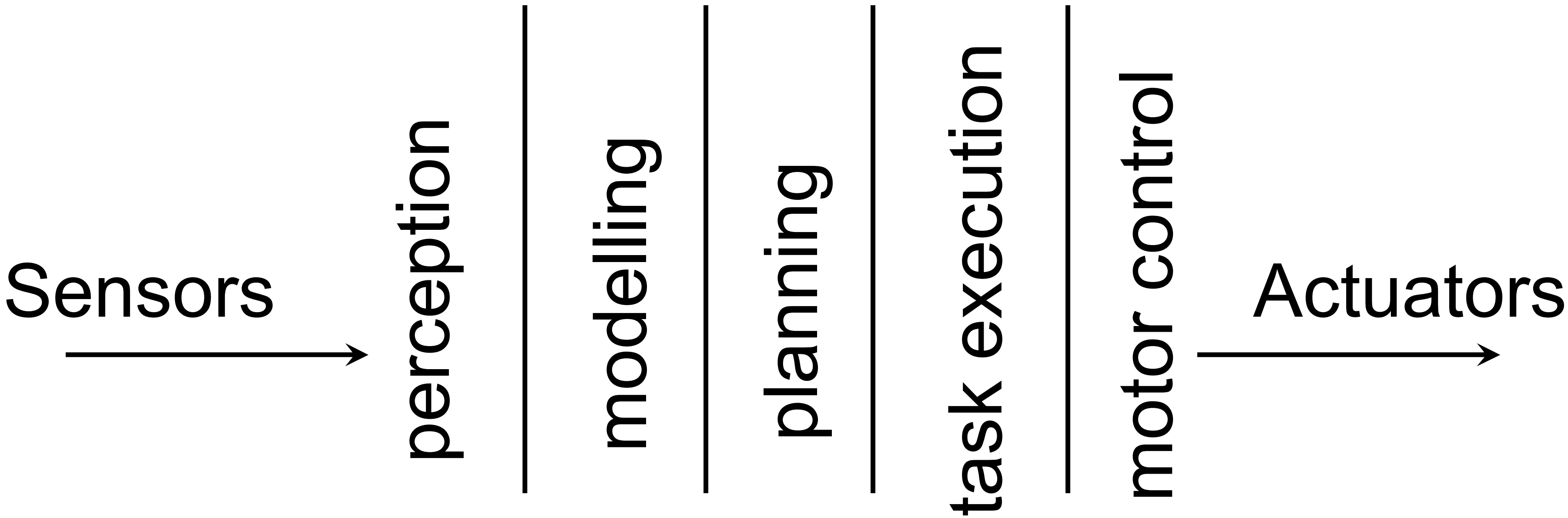
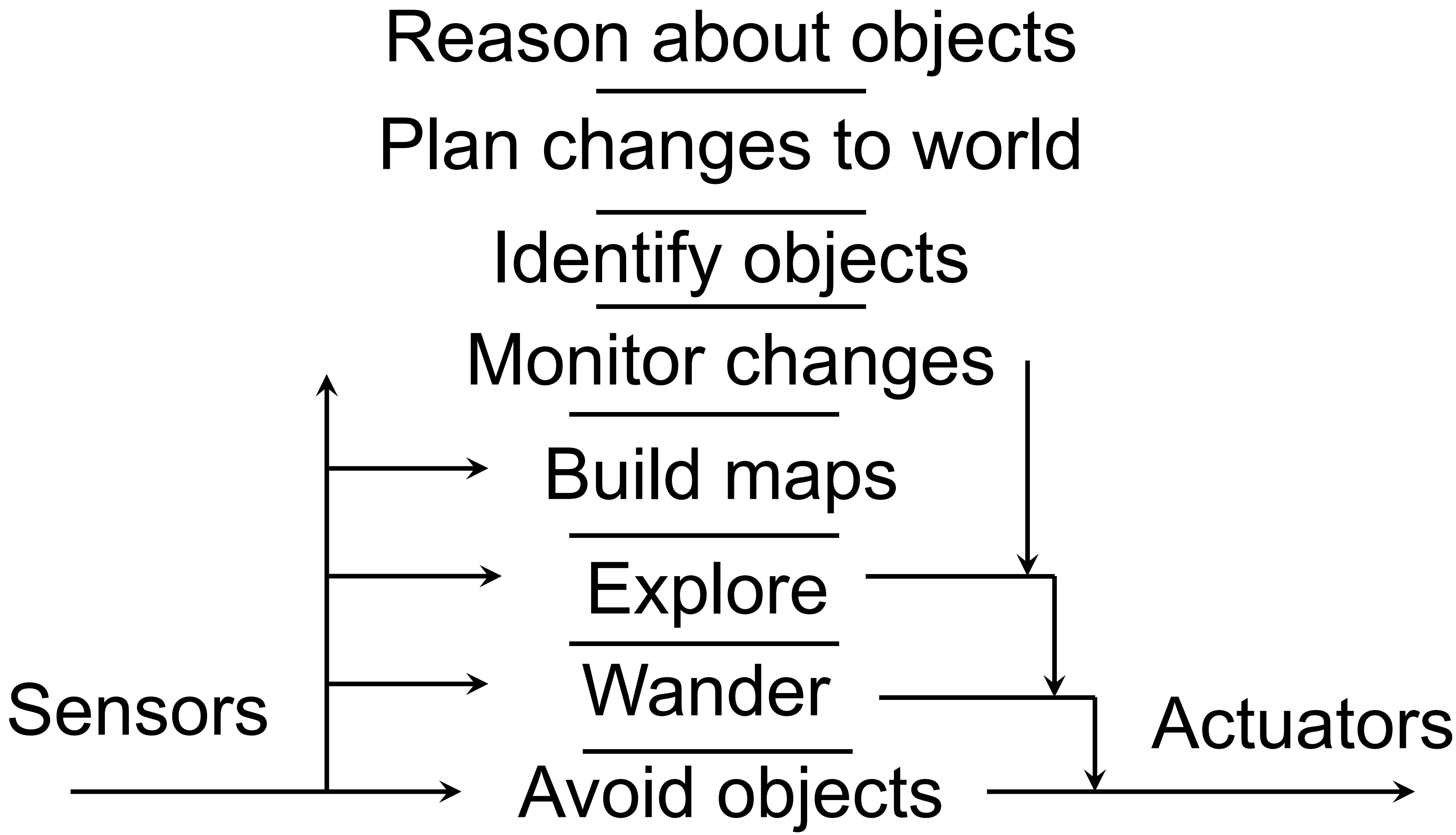
Traditional sense-plan-act approach suggests a ‘vertical’ (serial) task decomposition



An alternative to the ‘vertical’ approach is a ‘horizontal’ (parallel) task decomposition



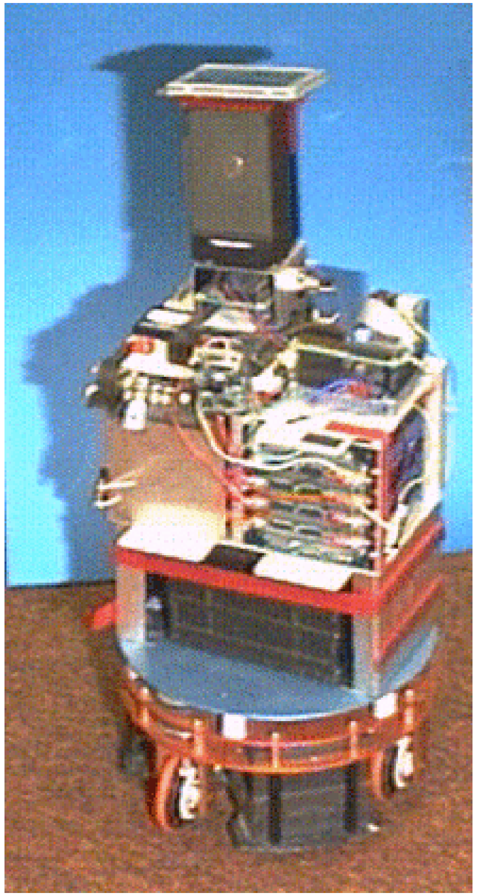
The behaviour-based approach

- Robot architecture is designed around a collection of behaviours:
  - Typically, these are reactive, or use only local memory and minimalist representations
  - Exploit physics and environmental interaction
- Each behaviour should function on its own as a complete sensorimotor loop in the real world (i.e. modular, but always building a complete agent)

E.g. subsumption architecture proposed by Brooks (1986)

- Decompose problem into layers of competence
- Each layer uses sensors, actuators and control
- Build and debug lowest layers first
- Add new layers without changing lower ones
- New layers will 'subsume' the output of lower layers

E.g. 'Polly' (Horswill, 1993)

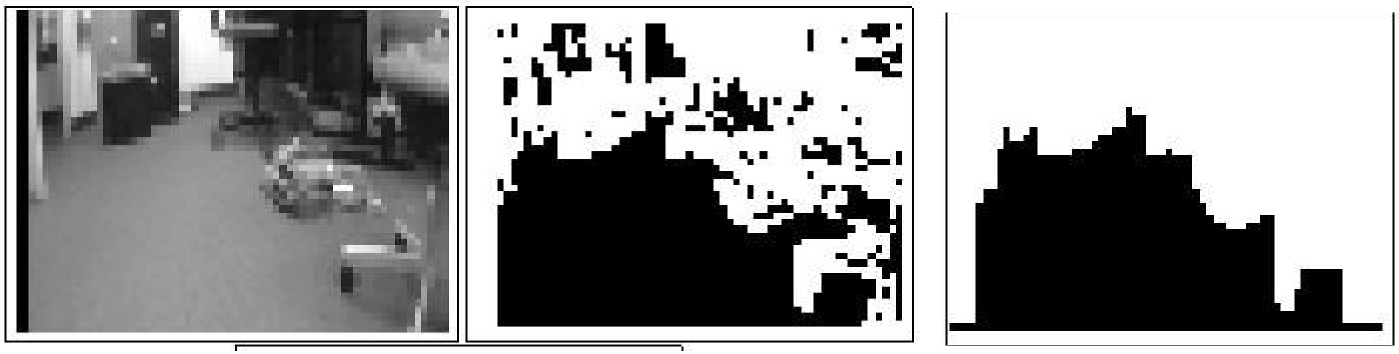


Subsumption on ‘Polly’: layer 0: avoid hazards

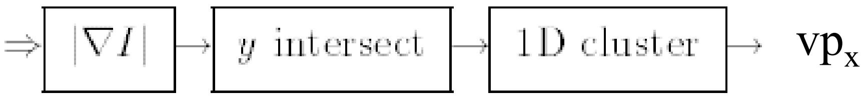
- Bump reflex: direct mapping from bump switches to motor controller to reverse and turn
- Allows sufficiently rapid response
- Actually disconnects main processor

Subsumption on 'Polly': layer 1: low level navigation

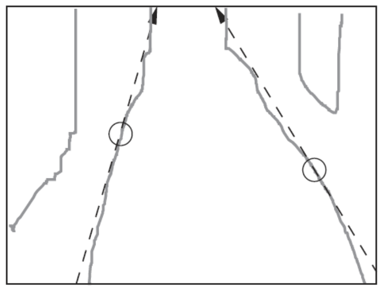
- Exploit physics of environment



- Texture filter to find free space/obstacles



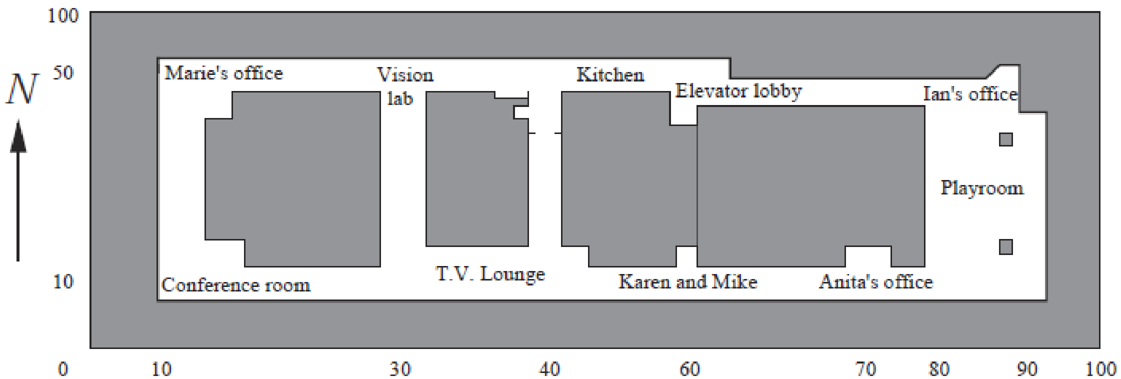
$$\frac{d\theta}{dt} = -\alpha \left(vp_x - \frac{\text{width}}{2} \right)$$



- Line detection to find corridor vanishing point vp_x

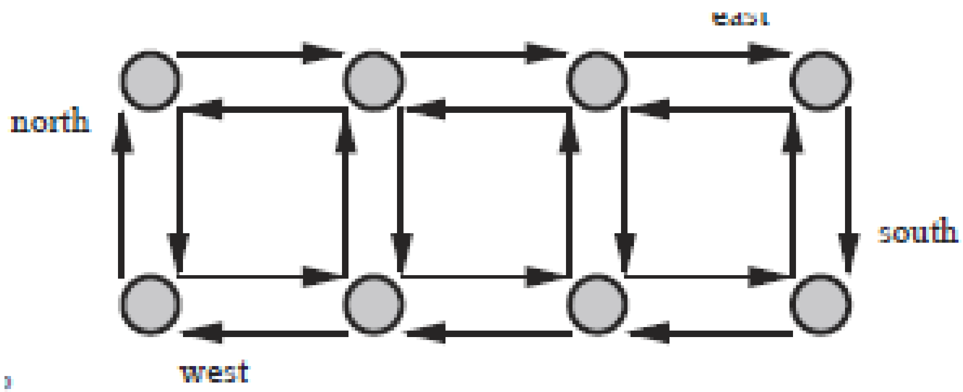
Subsumption on ‘Polly’: layer 2: ‘high level’ navigation

- Reactive place recognition: 32 ‘place frames’



Kitchen	
Position	(50, 40)
Direction	west
Veer	0
Image	...

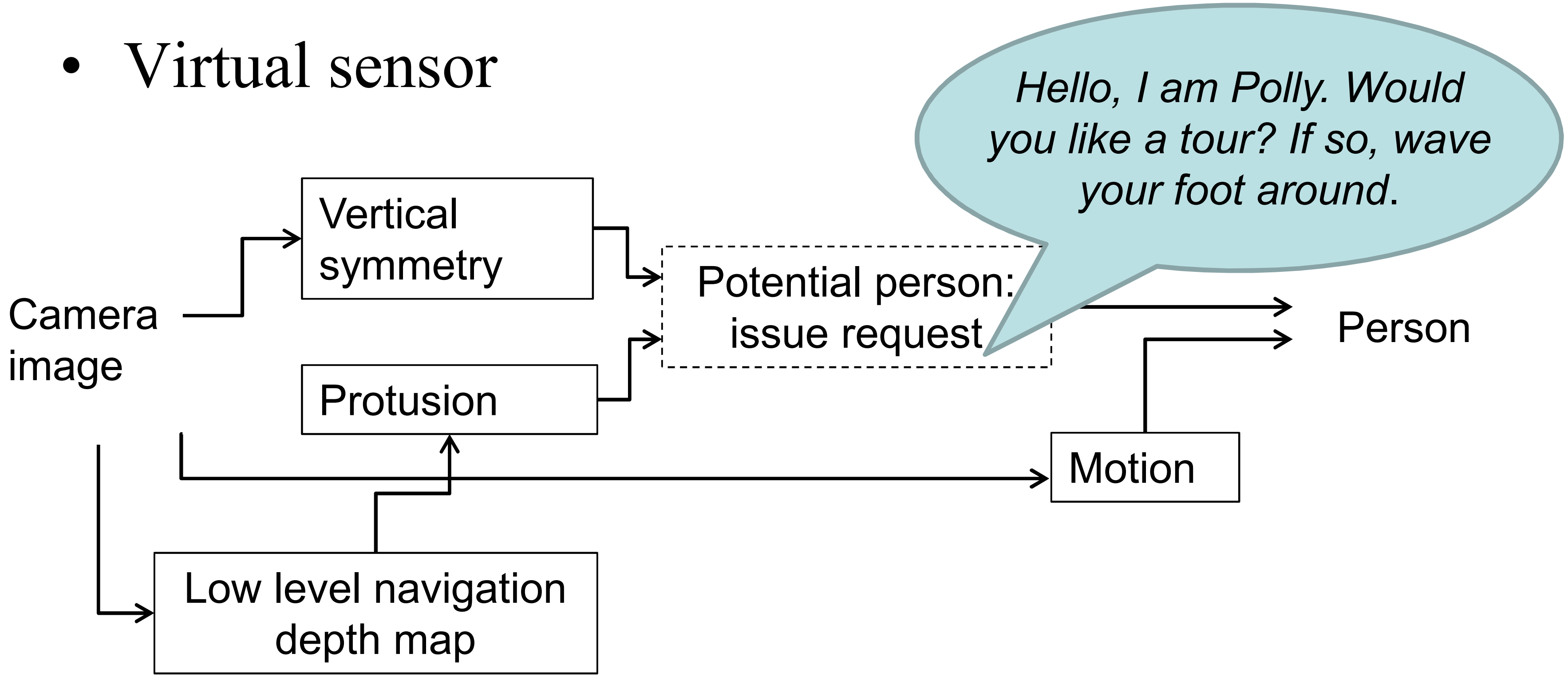
- Corridor following, so can reduce map to simple grid



- Navigator makes turn request at junctions

Subsumption on 'Polly': layer 3: person recognition

- Virtual sensor



Subsumption on ‘Polly’: layer 4: tour sequence

Event	Speech
Polly approaches visitor	Hello. I am Polly. Would you like a tour? If so, wave your foot around.
Visitor waves foot	Thank you. Please stand to one side.
Visitor moves	Thank you. Please follow me.
Polly drives	I can avoid obstacles, follow corridors, recognize places, and navigate from point to point.
Keeps driving	My vision system runs at 15 frames per second on a low cost computer
Robot passes vision lab	On the right here is the vision lab. By the way, I don’t understand anything I’m saying.
Robot enters T.V. lounge	This is the T.V. lounge. We waste a lot of time here.
Passes office	This is Karen and Mike’s office.
Passes office	This is the office of Anita Flynn.
Enters playroom	This is the playroom. This is the end of the tour. Thank you and have a nice day.
Robot drives off.	

Some advantages of the horizontal approach:

- Don't have to build all parts before testing on robot
- Immediate appreciation of effects of embodiment and situatedness, possibility of reactive solutions
- Multiple goals pursued in parallel, late decision
- Multiple sensors without requiring fusion
- Each layer adds competence to already working robot – graceful degradation if higher level fails
- Can map onto hardware e.g. new processors for each new level of behaviour - additivity

Some problems of the horizontal approach:

- Hard to predict/verify the emergent outcome of the combined behaviours
- Have to decide how behaviours will interact:
  - Hierarchical inhibition (e.g. subsumption architecture)
  - Mixed outputs (e.g. motor schema architecture)
  - Action selection mechanism:
    - through bottom up emergent process
    - through top-down control (see hybrid control lecture)

Motor schema architecture proposed by Arkin (1989)

- Schemas: independent asynchronous processes taking sensor inputs and generating velocity vectors
  - Move-to-goal: $V_{magnitude} = fixed\ gain, V_{direction} = perceived\ goal$
  - Avoid-static-obstacle:

$$O_{magnitude} = \begin{cases} 0\ for\ d > S \\ \frac{S-d}{S-R} * G\ \ for\ R < d \leq S \\ \infty\ \ for\ d \leq R \end{cases}$$

$$O_{direction} = line\ from\ obstacle\ centre\ to\ robot$$

  - Noise: $N_{magnitude} = fixed\ gain, N_{direction} = random\ change\ every\ p\ steps$
- Motor fusion: A weighted sum of the vectors determines the current reaction of the robot

Motor schema architecture

- Similar to potential field method, but only ever calculate the local vectors
- Relative gain of each behaviour can be varied according to robot's current mission state
  - E.g. high gain noise for exploring, low gain noise when approaching goal (keeping some noise as 'behavioural grease' to avoid local minima)

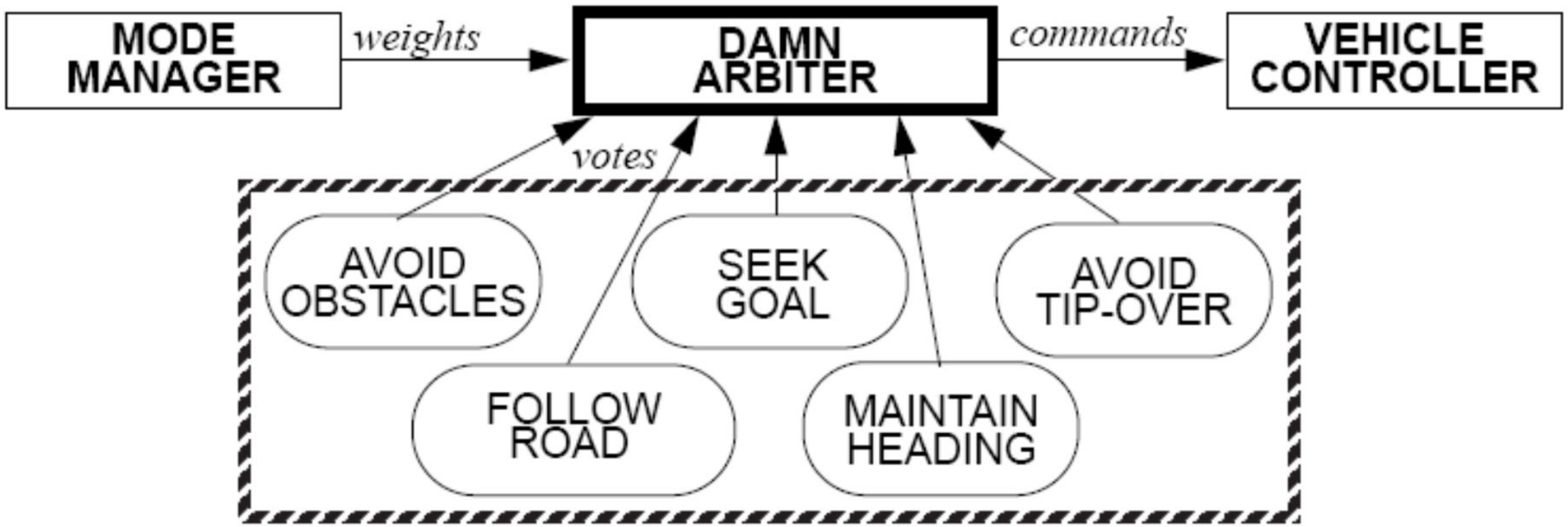
How could probabilistic approach be applied to adjust gains?

Action selection architectures

- A fixed hierarchy (as in subsumption) has to be predetermined and is not flexible to opportunities
- Motor fusion does not always produce the appropriate responses (particularly if behaviours conflict)
- Alternative is to have some form of ‘action selection’ mechanism between behaviours, e.g.:
  - Winner take all network
  - Fuzzy logic
  - Multiple objective optimisation
  - Reinforcement learning or other adaptive methods
- More recent/complex systems may use several selection mechanisms, according to task and situation

DAMN (Distributed architecture for mobile navigation) proposed by Rosenblatt (1995)

- As before have set of parallel asynchronous behaviours producing possible action outputs
- Final output determined by ‘arbiters’ that count the weighted votes for each action



Behaviour based approach: Conclusions

- Produced some very robust and successful robots:
  - Still very widely used in robot and agent approaches
  - But no continuous evolution to higher capabilities…?
- Wide influence across AI and related fields:
  - Importance of embodiment and situatedness; solving problems with physics and hardware as well as software
  - Possibilities for low-level sensorimotor coupling, exploiting environments, emergent behaviours
  - Use of world rather than internal representations
  - New focus on action selection as critical problem to solve

Conclusions

- But arbitrary and difficult to design emergent behaviour for a given task.
  – Architectures do not impose strong constraints
- Options?
  – Build up toolbox of techniques
  – Use learning or evolutionary methods
  – Copy existing systems (i.e. biology)
  – Formalise interactions as dynamical systems
- Difficult to do some traditional (and useful) tasks.
  – Increasingly common to adopt ‘hybrid’ approach, e.g. classical planner operating on top of basic behaviours

References

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