G53DIA:
Designing Intelligent Agents

Lecture 7: Hybrid Architectures

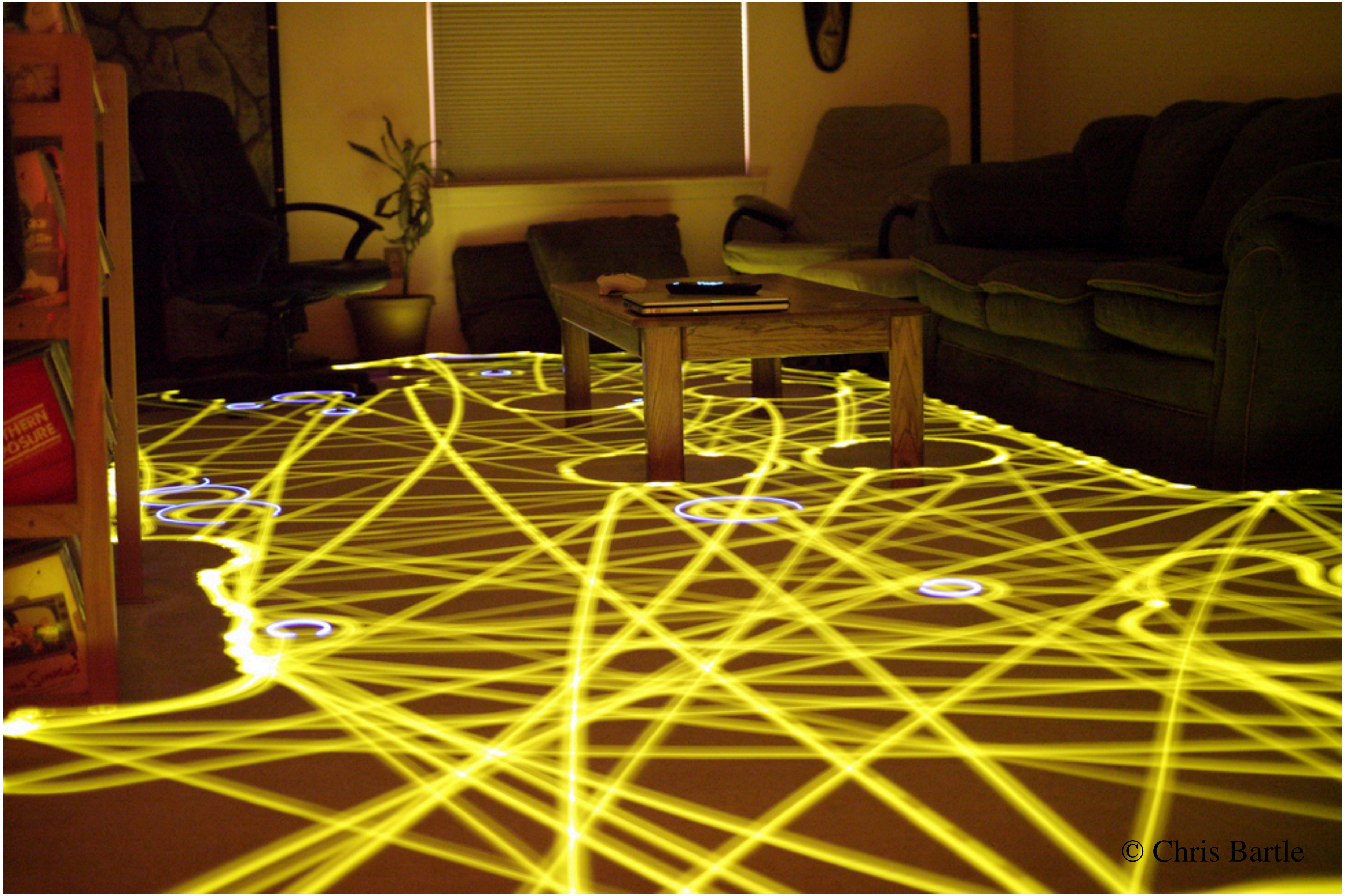
Brian Logan
School of Computer Science
bsl@cs.nott.ac.uk

Outline of this lecture

- comparison of reactive & deliberative architectures
- hybrid architectures
- problems of integrating representations and timescales
- problems of controlling interactions between components
- examples:
  - TouringMachines
  - Xavier

Example: Roomba

- simple robot vacuum cleaner
- infra-red & bump sensors for collision avoidance, stair sensor to detect drops and a dirt (dust) sensor
- executes a modified random walk with simple behaviours to avoid obstacles, circle in dirty areas and untangle from cables
- essentially a *reactive architecture*


© Chris Bartle

Advantages of reactive architectures

- a reactive architecture with state can produce *any* kind of behaviour
- requires no, or very simple, representations of the environment
- fast (often real-time) response to changes in the environment
- easy to produce agents to solve simple problems

Disadvantages of reactive architectures

- can't form complex representations, or consider alternative plans/ solutions to a problem
- every solution to every problem must be coded in advance, either by the designer of the system, or by evolution
  - each new behaviour added may interfere with existing behaviours
  - possible interactions between behaviours must be anticipated when designing or extending the system
- agent programs for complex problems can be *very* large

Reactive task environments

Reactive architectures are a good choice for task environments where:

- **goals**: small number of simple (ascribed) achievement and maintenance goals, typically no constraints on how goals are achieved
- **percepts**: observable, dynamic, nondeterministic and continuous
- **actions**: may be fallible, may have differing utilities and costs, agent may be mobile but typically doesn't communicate with other agents

Example: Trilobite

- more complex robot vacuum cleaner
- sonar, infra-red & bump sensors for collision avoidance, stair sensor to avoid drops and a dirt sensor
- initially cleans along the edges of the room, building a map of the room and obstacles
- then plans and executes an 'optimum' path to clean the rest of the room
- essentially a *deliberative architecture*

Advantages of deliberative architectures

- allows us to code a *general procedure* for finding a solution to a *class of problems*
  - may be better than reactive systems at coping with novel problems
  - we may be able to get a correct or even an optimal answer
- useful when the penalty for incorrect actions is high, e.g., when the environment is hazardous

Disadvantages of deliberative architectures

- requires accurate models of the current state of the environment and how it will change

- hard to offer real-time guarantees on performance:

  – deliberation takes more time than simply reacting

  – deliberation takes an unpredictable amount of time

Deliberative task environments

Deliberative architectures are a good choice for task environments where:

- **goals:** strongly committed to its top-level goals, goals are not time-dependent, may have constraints on how goals are achieved

- **percepts:** partially observable, static, deterministic, discrete

- **actions:** infallible, may have differing utilities and costs, agent is typically immobile, may communicate with other agents

Reactive *vs* Deliberative architectures

- reactive architectures have to code every solution to every problem in advance
- deliberative architectures allow us to code a general procedure for finding a solutions to a class of problems in advance
- a reactive architecture will typically require *less time and space* to solve any *single* problem instance than a deliberative architecture
- a deliberative architecture will typically be *more space efficient* than an equivalent reactive architecture since it can solve a class of problems in a fixed amount of space, whereas a reactive architecture requires space proportional to the number of problem instances

Hybrid architectures

- a *hybrid* architecture has both reactive and deliberative components
- hybrid architectures attempt to obtain the advantages of both reactive and deliberative architectures without their disadvantages
- the reactive and deliberative components are typically organised in *layers*:
  - the reactive components are responsible for relatively simple, low-level behaviours
  - the deliberative components are responsible for organising and sequencing the reactive behaviours
- a key problem is *integration* of the reactive and deliberative layers

Differences in representations

- *reactive layer* typically uses very simple representations of the current or previous state of the environment, e.g., agent-centred, vector based representations
- *deliberative layer* uses complex counterfactual representations, for example representations of objects and their attributes in world coordinates
- how can the representations used by the deliberative layer be derived from the information at the reactive layer?

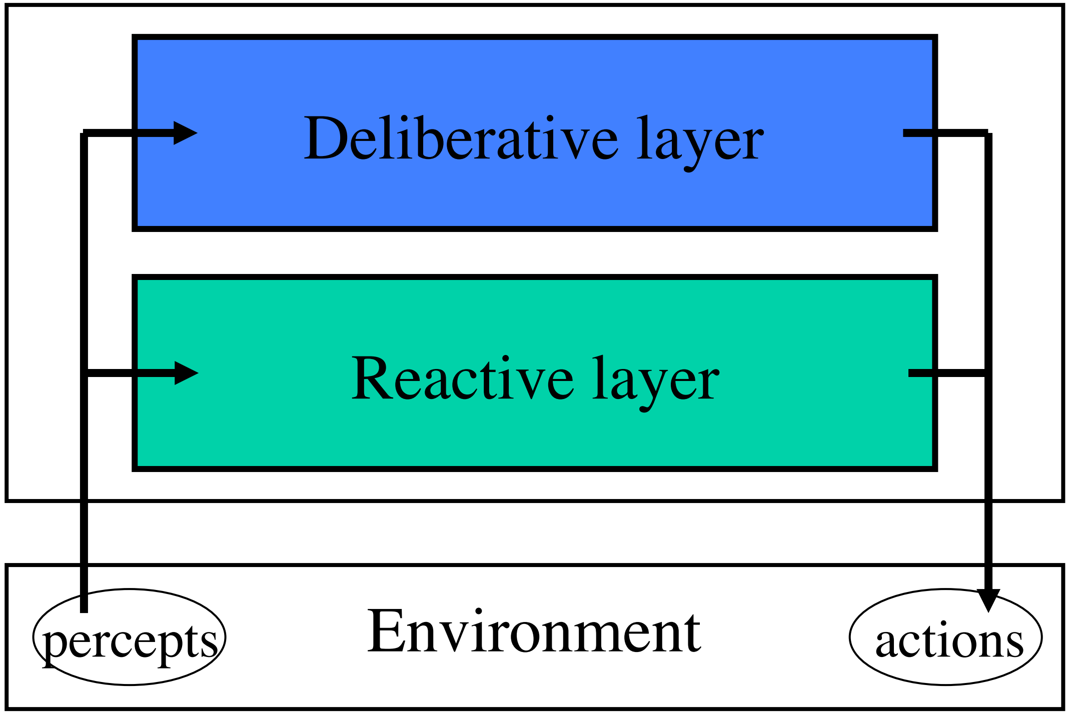
Differences in timescales

- *reactive layer* typically works over very short timescales in tight, sensor-motor feedback loops
- *deliberative layer* works on much longer timescales, from minutes to hours or even longer
- how can high-level actions at the deliberative layer be related to fine-grained actions at the reactive layer?

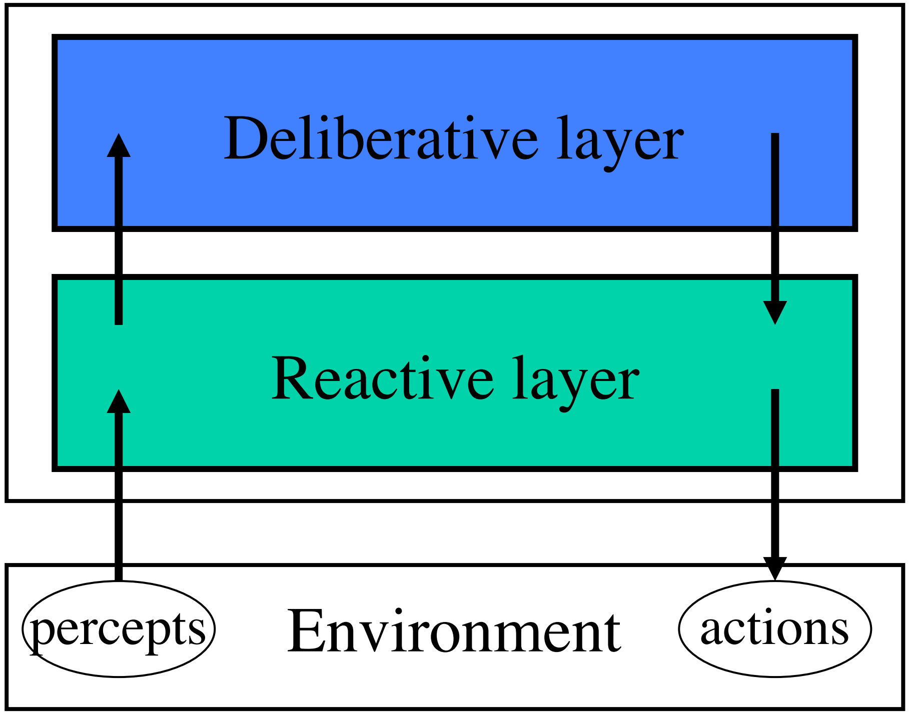
Control

- *decentralised control*: layers operate concurrently and independently, processing sensor data and generating actions
- *hierarchical control*: layers operate serially, with higher-level, deliberative layers controlling the execution of low-level reactive layers
- *concurrent control*: layers operate concurrently and can modify the behaviour of ‘adjacent’ layers

Decentralised control

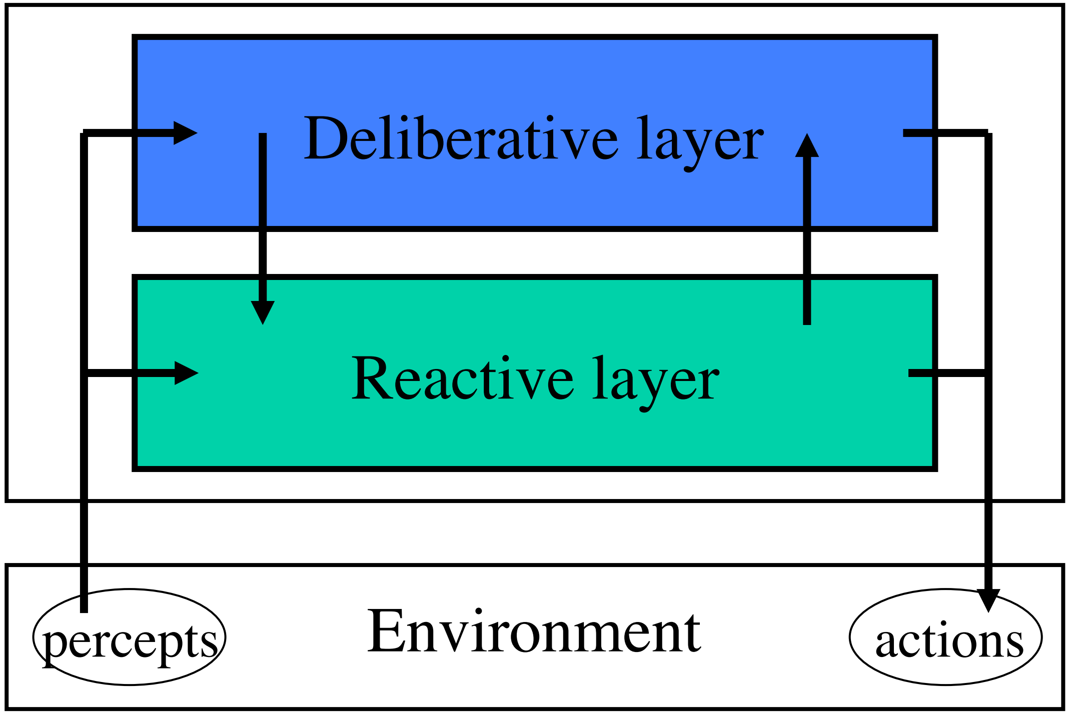


Hierarchical control



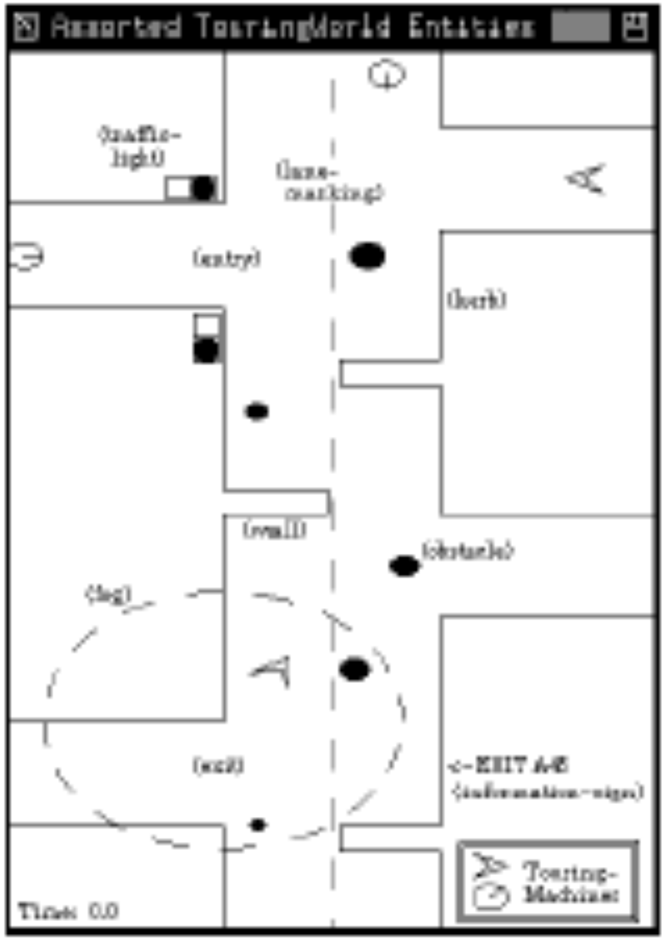
Example: Fred & Ginger

Concurrent control

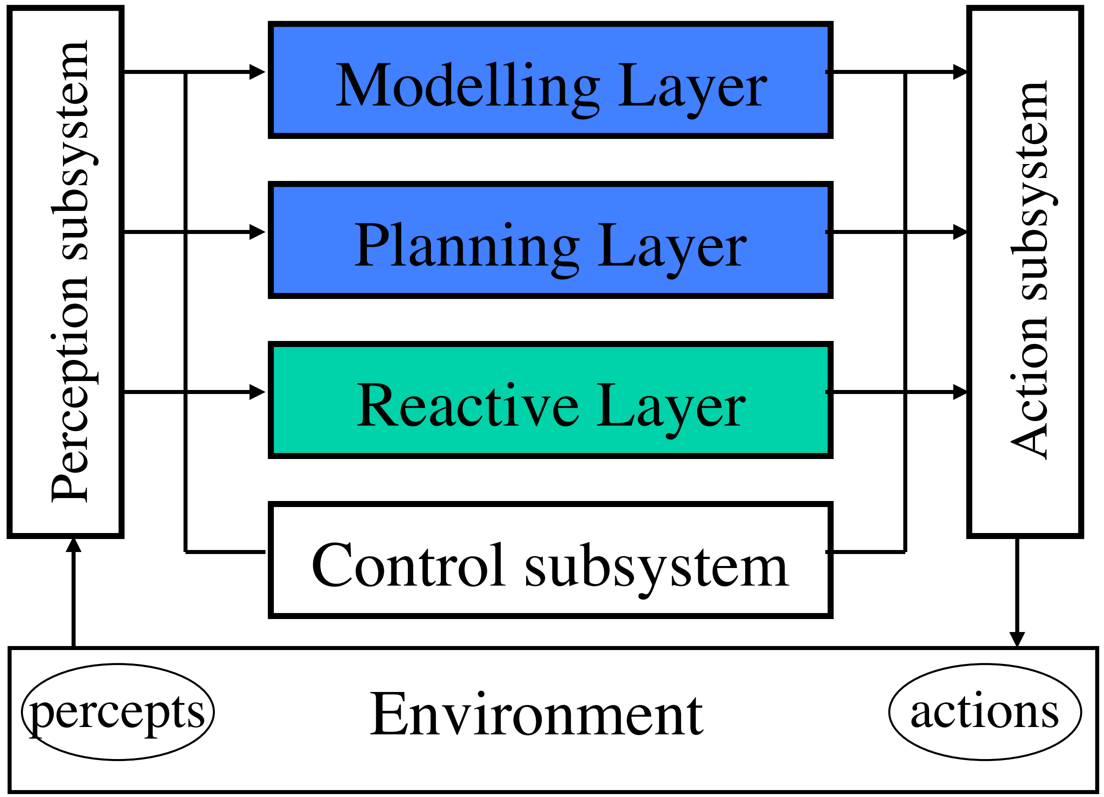


Example TouringMachines

- TouringMachines are autonomous (simulated) vehicles which drive along streets in the TouringWorld
  - the environment contains obstacles, traffic lights, rain (which affects braking distance) and fog (which changes the TouringMachines' visual field and range)
  - the TouringMachines goals are to reach a given location by a specified time, avoiding collisions with obstacles and other TouringMachines and obeying the traffic regulations.



TouringMachines architecture



Reactive layer

- responsible for producing an immediate response to changes in the environment
- e.g., obstacle avoidance
- implemented as a set of condition action rules which map percepts directly to actions.
- the rules can only refer to the agent's current state and they can't do any explicit reasoning about the world

Planning layer

- responsible for achieving simple goals, e.g., moving from place to place
  - implemented as library of predefined *plan schemas* which are elaborated at run time
  - to achieve a goal, the planning layer attempts to find a schema that matches that goal
  - if a schema contains subgoals, the planning layer attempts to find schemas in the plan library that match each sub-goal

Modelling layer

- responsible for representing other entities (agents) in the world, including the agent itself
  - predicts conflicts between agents and (autonomously) generates new goals to resolve these conflicts
  - these goals are passed to the planning layer which plans to achieve them in the normal way

Control subsystem

- responsible for deciding which of the reactive, planning and modelling layers should have control of the agent at any given time
- implemented as a set of *control rules* which can either
  - suppress percepts output by the perceptual subsystem; or
  - censor actions generated by the control layers
- e.g., a control rule may prevent the reactive layer from ever knowing that a particular obstacle has been perceived, if another layer is more appropriate for dealing with this type of obstacle

Integration

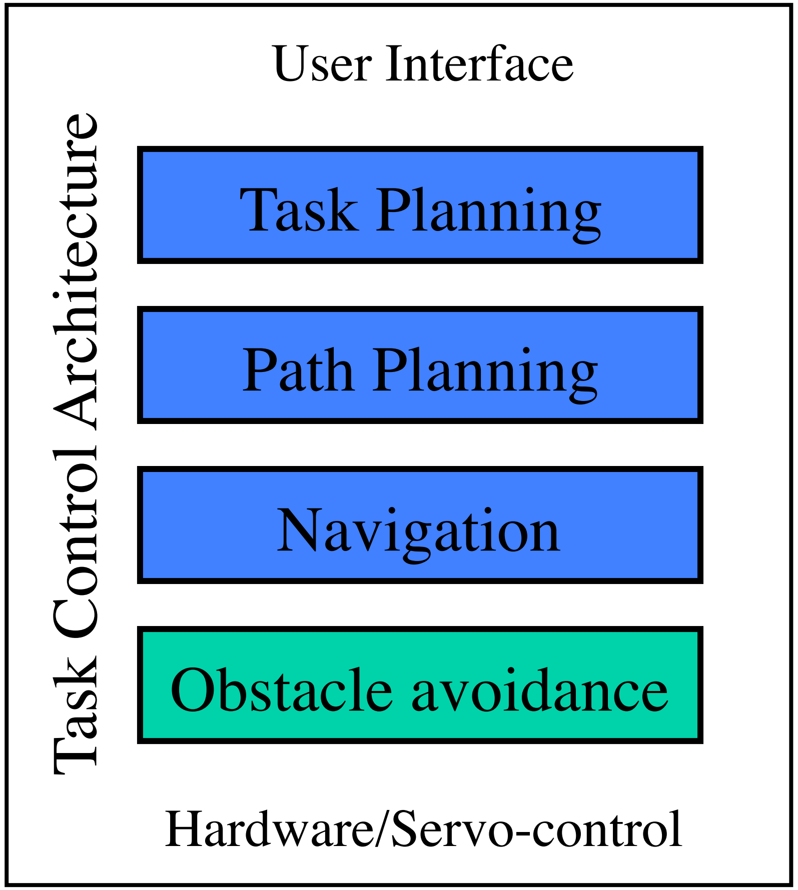
- the TouringMachines architecture can be viewed as hierarchical in the sense that there is a single subsystem (layer) which effectively makes all the control decisions
  - in this sort of architecture, the designer must potentially consider all possible interactions between the layers
  - if there are *n* layers and each layer can suggest *k* actions, this means that there are k^n interactions to be considered

Xavier's percepts and actions

- sensors:
  - bump panels
  - odometers
  - 24 sonar sensors
  - front-pointing laser striper
  - colour camera
- actuators:
  - 4 drive wheels
  - speech output
  - Wavelan wireless ethernet card

- on-board processing: two 66MHz i486 computers & a i486 laptop (all running Linux)

Xavier's architecture



Task planning

- task planning is performed using the PRODIGY partial order planner
- integrates new asynchronous requests into the current plan
- prioritises tasks
- opportunistically achieves compatible tasks
- determines the order in which to interleave the actions required for each task
- consults the path planner to determine the expected travel time between two locations

Path planning

- determines how to travel efficiently from one location to another
- uses a decision theoretic approach to choose plans with high expected utility
- uses sensitivity analysis to determine which alternatives to consider
- actuator and sensor uncertainty complicates path planning
  - the robot may not be able to follow a path accurately
  - the shortest distance path is not necessarily the fastest

Navigation

- navigation layer directs the robot to a given goal location
- uses Partially Observable Markov Decision Process models
- maintains a probability distribution of where the robot is at all times and chooses actions based on that distribution
- generally follows the path suggested by the path planner
- it may deviate from the desired path since it has to deal with sensor and motor uncertainty–if an error is detected, it issues corrective actions that re-orient the robot towards its goal

Obstacle avoidance

- obstacle avoidance is performed using a curvature velocity method
- keeps the robot moving in the desired direction, while avoiding static and dynamic obstacles (e.g., tables and people)
- takes the robot’s dynamics into account
- real time optimisation problem that combines safety, speed and progress along the desired heading

Integration

- reliability and efficiency is achieved using reliable and efficient components and through the interaction of the layers
- each layer uses a more abstract representations of the data from lower layers
- higher layers can guide the lower layers into regions of the environment where safe and efficient navigation can take place
- lower layers take care of details abstracted away by higher layers
- lower layers propagate failures up to higher layers when they find they can't handle certain exceptional situations

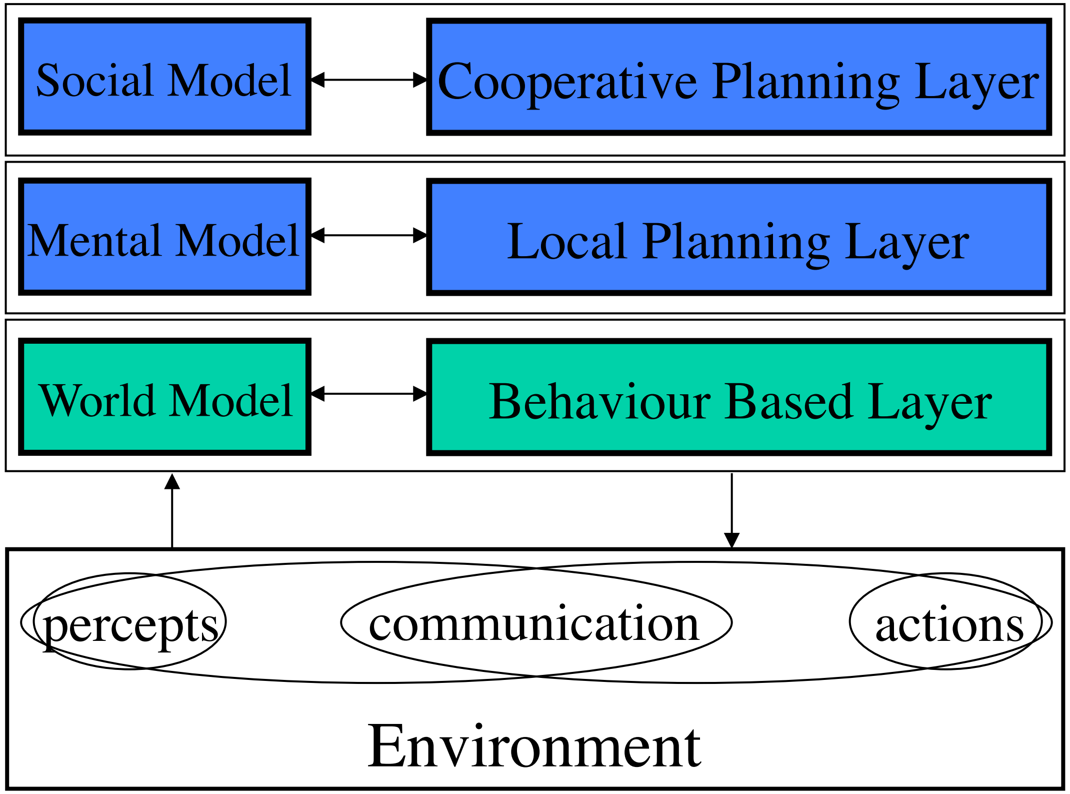
Xavier’s task environment

Xavier takes the elevator

Example: InteRRaP

- InteRRaP is a hybrid architecture which integrates behaviour-based control, deliberation and joint planning
- used in FORKS—a software and hardware simulation of an automated loading dock
- agents receive orders to load and unload trucks
- while performing their tasks they may run into conflicts with other agents, e.g., if both agents try to move to the same place at the same time

InteRRaP architecture



InteRRaP layers

The architecture is has three layers:

- *behaviour-based layer* allows the agent to react to critical situations (using reactor *patterns of behaviour*) and to deal with routine situations (using procedure *patterns of behaviour*)

- *local planning layer* allows the agent to do domain dependent planning, using information from the *world model* together with the agents current goals and intentions held in the *mental model*

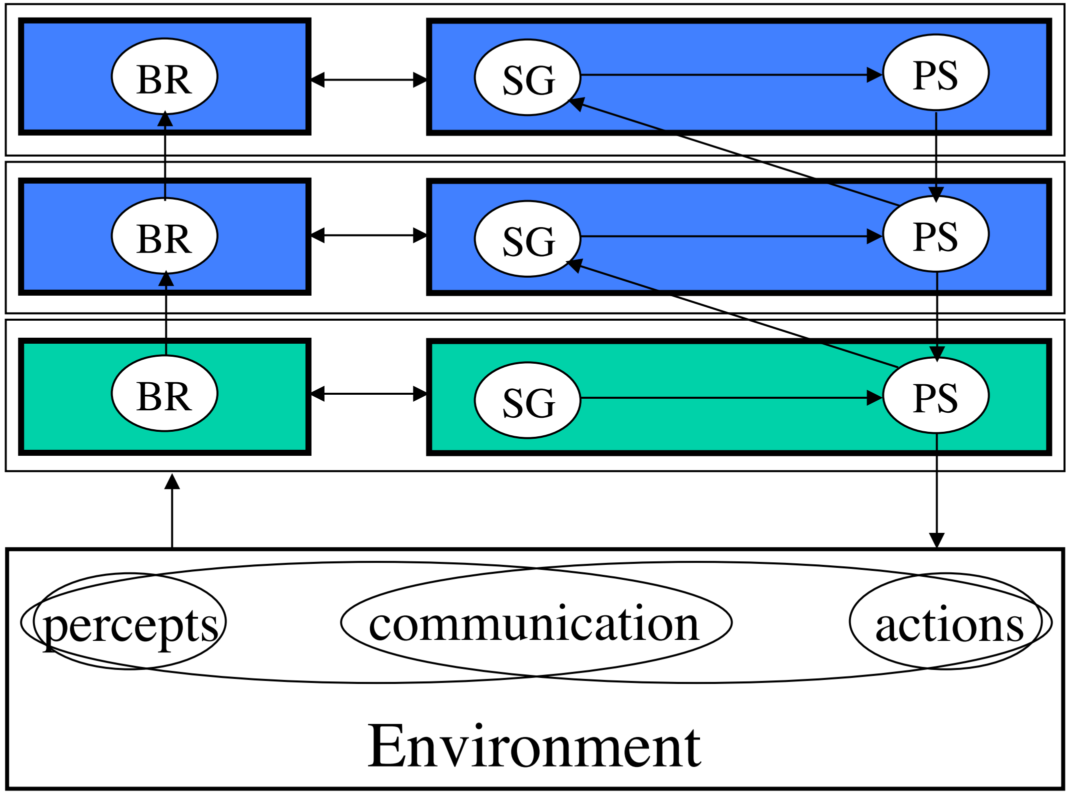
- *cooperative planning layer* extends the planning functionality to joint plans, i.e., plans involving multiple agents which resolve conflicts and allow the agents to cooperate

InteRRaP layer functions

Each layer implements 3 functions:

- Belief Revision (BR): belief revision and knowledge abstraction, which maps the agent's current percepts and old beliefs to new beliefs
- Situation Recognition and Goal Activation (SG): derives new goals from the agent's new beliefs and its current goals
- Planning and Scheduling (PS): derives a set of new intentions (commitments to courses of action) based on the agent's current goals (selected by SG) and the agent's current intentions

InteRRaP architecture detail



The next lecture

Project description