Introduction to **Mobile Robots**

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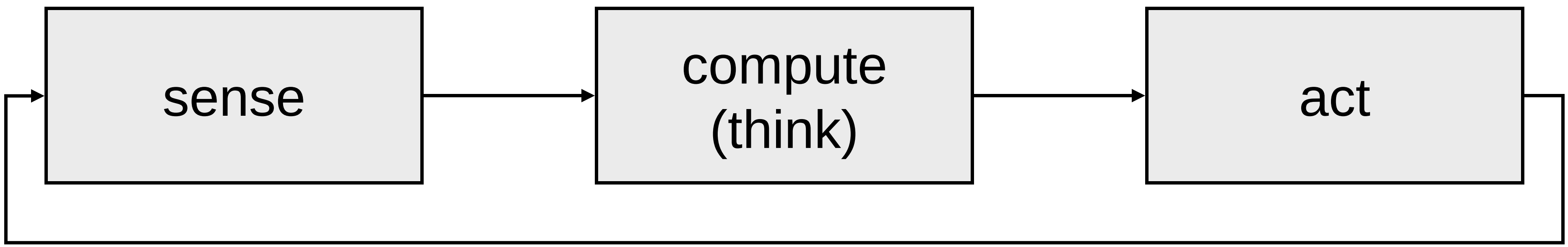
Control Models

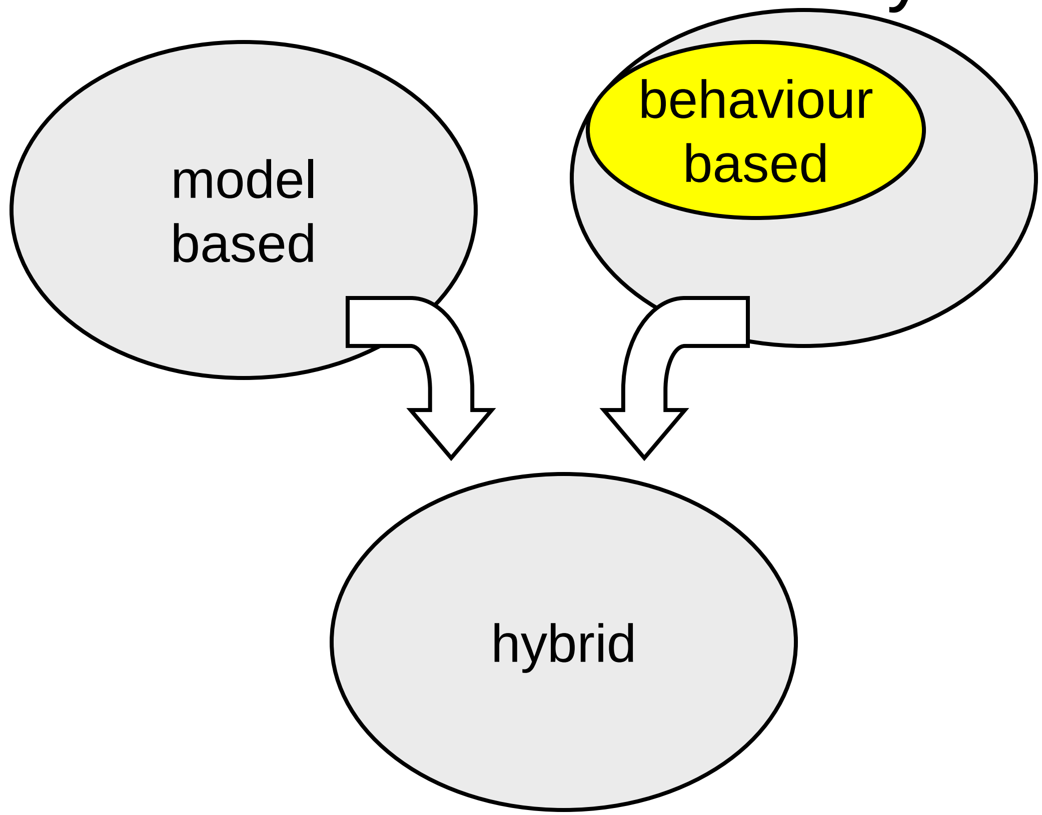
The Control Cycle

- A fundamental methodology derived in the early days of robotics from engineering principles is the *sense-think-act* cycle
  - the principle is to continuously attempt to minimise the error between the actual state and the desired state
    - based on control theory



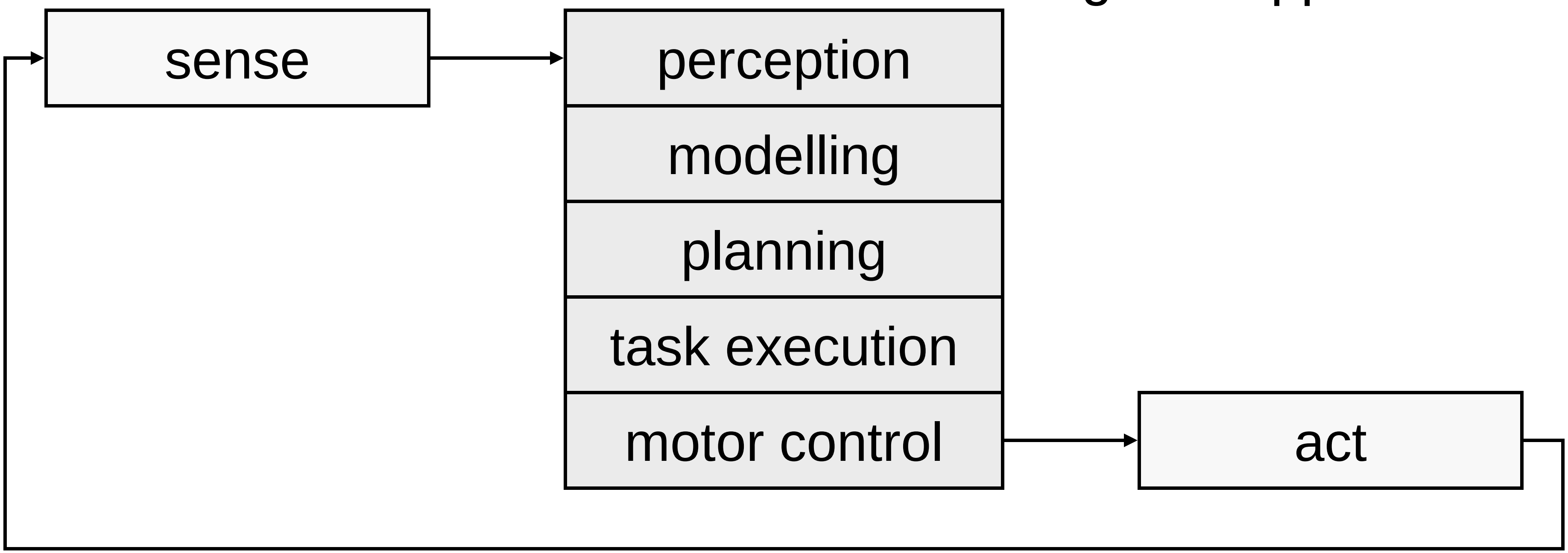
Control Architectures

- A variety of different approaches have been tried for implementing the *sense-think-act* control cycle
- These approaches can be categorised as
  - model-based
  - reactive
  - hybrid



Model Based

- A symbolic internal 'world-model' is maintained
  - the sub-tasks are *decomposed* into functional layers
  - similar to 'classical' artificial intelligence approach



Problems with Models

- An adequate, accurate and up-to-date model must be maintained at all times
  - this is very difficult in practice!
  - what if sensors detect an object that hasn't been defined
- A model-based system is extremely brittle
  - if one of the functional layers fails (e.g. hardware problems, software bugs), then the whole system fails
- Significant processing power is required
  - maintaining the model takes time, so slow responses!?
- Despite much effort, little progress was made!

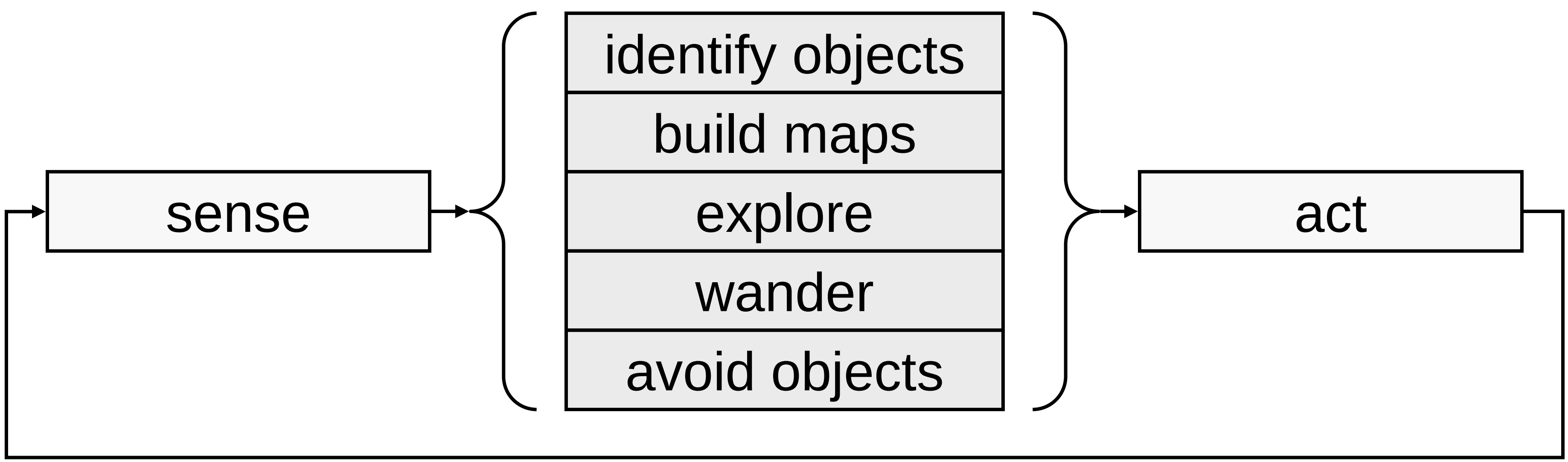
Reactive Robotics

Reactive Controllers

- In order to try to overcome the shortcomings of model-based robots, modern approaches have centred predominantly on simple *reactive* systems with minimal amounts of computation
  - ‘model-free systems’
- More correctly, the models are *simple* and *implicit*
  - the systems do not use symbolic models but, for example, a rule-set which tells a robot how to react to a corner when following a wall may be considered to be a simple, implicit model fragment
    - it implicitly encodes assumptions about the environment

Behaviour Based

- The control system is broken down into horizontal modules, or *behaviours*, that run in parallel
  - each behaviour has direct access to sensor readings and can control the robot's motors directly



Behaviour Advantages

- It supports multiple goals and is more efficient
  - there is no functional hierarchy between layers
    - one layer does not call another layer
  - each layer can work on different goals in parallel
  - communication between layers is achieved via message passing which need not be synchronised
- The system is easier to design, debug and extend
  - each module can be designed and tested individually
- The system is robust
  - if one module fails, e.g. *wander*, then other layers, e.g. *avoid obstacles*, still function and behave correctly

Behaviour Limitations

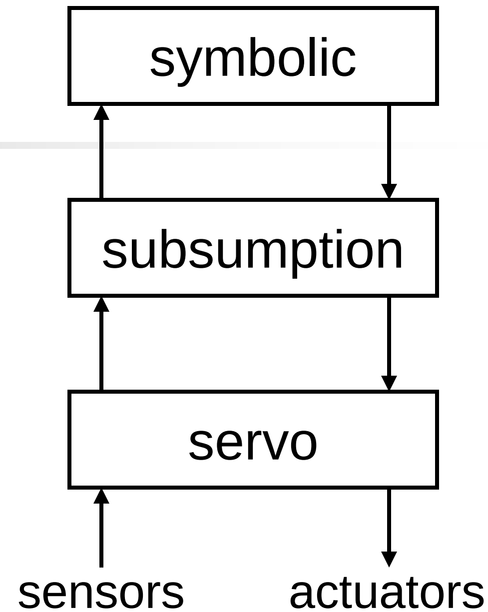
- It is extremely difficult to implement plans
  - in pure form a behaviour-based robot has no memory (not even an internal state memory) and so is unable to follow an externally specified sequences of actions
- It can be very hard to predict how a large number of multiple behaviours may interact
  - *emergent behaviour* is the term given to unexpected behaviour that comes about through these interactions
    - sometimes it is useful, sometimes it is not!
- The robot can get trapped in a *limit cycle*
  - trapped in a dead-end, repeatedly turning left then right

Other Approaches

Other Reactive Approaches

- Two other reactive approaches that are popular
- Potential field methods
  - a potential field is a concept from physics
    - e.g. the *gravitational field*
      - you do not need to be told which way to fall
      - planets do not need to plan how to move around the sun
    - obstacles exert hypothetical repulsive forces on the robot
- Motor schema navigation
  - multiple, concurrent schema generate separate behaviours which are summed to produce output
    - schema are dynamically created/destroyed as needed

Hybrid Approaches



- The *SSS* three-layer architecture
  - the *servo-subsumption-symbolic* architecture combines Brooks' architecture with a lower-level servo control level and a higher-level symbolic system [Connell]
  - I provides a neat way to combine the advantages of each architecture:
    - Quick response of servo
    - Robust response of reactive (subsumption)
    - Planning capabilities of model based (symbolic)

Learning Approaches

- Traditional learning techniques
  - rather than attempt to predefine and predict a symbolic model of the ‘real-world’, the robot learns how to operate and how to behave
- Evolutionary algorithms
  - using genetic algorithms to find good network weights
  - significant problems with evolving real solutions in reasonable time on current mobile robot hardware

Introduction to Sensors

Robot Sensors

- Sensors are devices that can sense and **measure** physical properties of the environment,
  - e.g. temperature, luminance, weight, size, etc.
- They deliver *low-level* information about the environment the robot is working in
- This information is
  - noisy (imprecise) and even contradictory and ambiguous
- Sensors and Detectors are similar but **NOT** equal

Sensor Characteristics

- All sensors are characterised by a number of properties that describe their capabilities
  - Sensitivity: (change of output) ÷ (change of input)
  - Linearity: constancy of (output ÷ input)
  - measurement range: difference between min. and max.
  - response time: time required for a change in input to cause a change in the output
  - Accuracy: difference between measured & actual
  - Repeatability: difference between repeated measures
  - Resolution: smallest observable increment
  - Bandwidth: range of frequencies it can respond to

Sensor Types

- It is impossible for us not to view the world in a human-centric manner, but this is not absolute:
  - vision is our main sense, as the human brain is dominated by a large visual cortex
  - the dog brain is dominated by an olfactory cortex, with 125 to 220 million smell-sensitive receptors in the olfactory bulb
  - cockroaches have 30,000 wind-sensitive hairs on legs
- There are many different types of sensor
  - many sense phenomena that humans cannot detect
    - e.g. magnetism, infra-red, ultra-violet, ultrasound, phase of light (e.g. polarised sun-glasses), etc.

Active vs. Passive

- Sensors can be broadly classified as either
  - *active*
    - radiating some form of energy into the environment
    - e.g.
      radar (radio direction and ranging)
      sonar (sound navigation and ranging)
      lidar (light direction and ranging)
  - *passive*
    - relying on energy emitted by various objects in environment
- It is tempting to imagine that passive sensors do not interfere with the environment
  - *ANY sensor may affect the environment*

Internal State vs. External State

- The variable that a Sensors reads can provide information either
  - *About the internal state of the Robot*
    - Internal variables, e.g. battery level
    - Self measurements, e.g. odometry
    - Time
  - *About the external environment*
    - External variables, e.g. outside temperature
    - Position relative to external objects, e.g. obtacles
    - Communications

Non-Visual Sensors

Proximity Sensors

- Tactile sensors allow obstacle *detection* but proximity sensors are needed for true obstacle *avoidance*
- Several technologies can detect the presence of particular fields without mechanical contact
  - magnetic reed switches
    - two thin magnetic strips of opposite polarity not quite touching
    - an external magnetic field closes the strip & makes contact
  - Hall effect sensors
    - small voltage generated across a conductor carrying current
  - inductive sensors, capacitive sensors
    - inductive sensors can detect presence of metallic objects
    - capacitive sensors can detect metallic or dielectric materials

Infrared Sensors

- Infrared sensors are probably the simplest type of non-contact sensor
  - widely used in mobile robotics to avoid obstacles
- They work by
  - emitting infrared light, (to differentiate emitted IR from ambient IR - e.g. lights, sun, etc.- , a code is added)
  - detecting any reflections off nearby surfaces
- In certain environments, with careful calibration, IR sensors can be used for object distance
  - requires uniform surface colours and structures

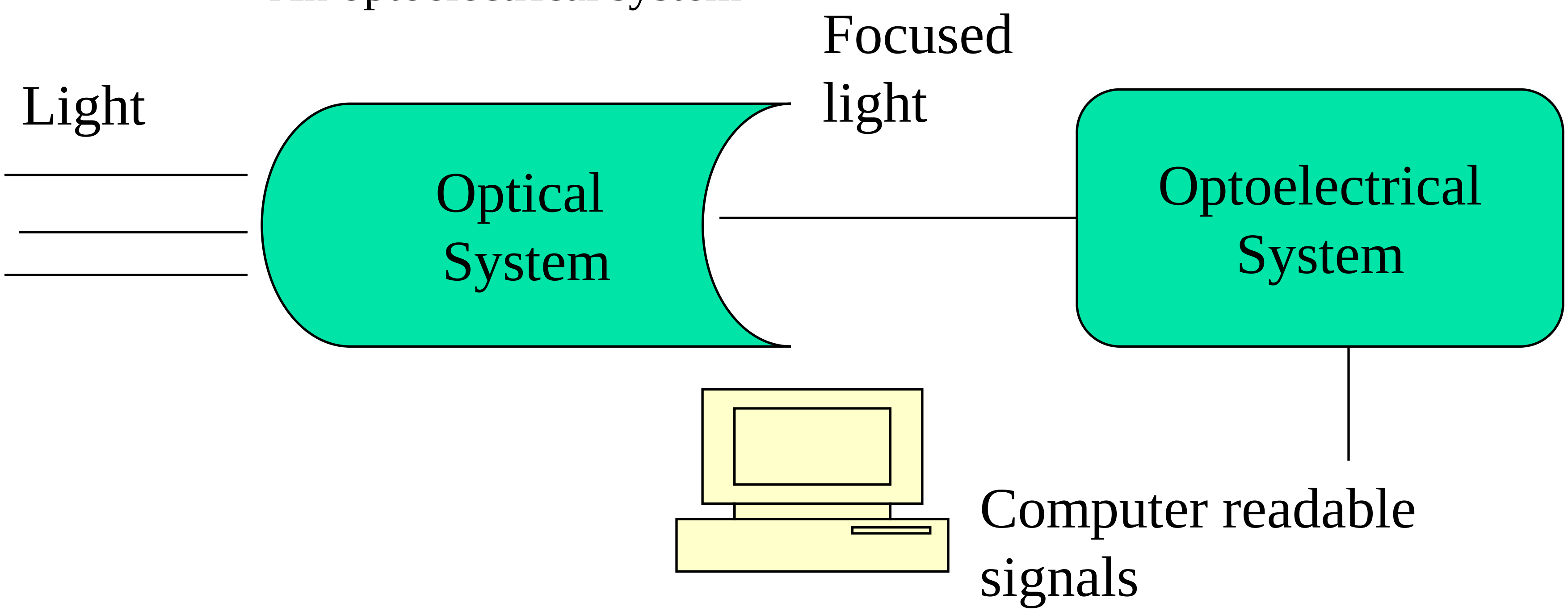
Sonar Sensors

- The fundamental principle of robot sonar sensors is the same as that used by bats
  - emit a chirp (e.g. 1.2 milliseconds)
    - a short powerful pulse of a range of frequencies of sound
  - its reflection off nearby surfaces is detected
- As the speed of sound in air is known (≈ 330 $m \cdot s^{-1}$) the distance to the object can be computed from the elapsed time between chirp and echo
  - minimum distance = 165 t_{chirp} (e.g. 21 cm at 1.2 ms)
  - maximum distance = 165 t_{wait} (e.g. 165 m at 1 s)
- Usually referred to as *ultrasonic* sensors

Visual Sensors

Visual Sensors

- Visual sensors are based on light. They consist of two main components:
  - An optical system
  - An optoelectrical system

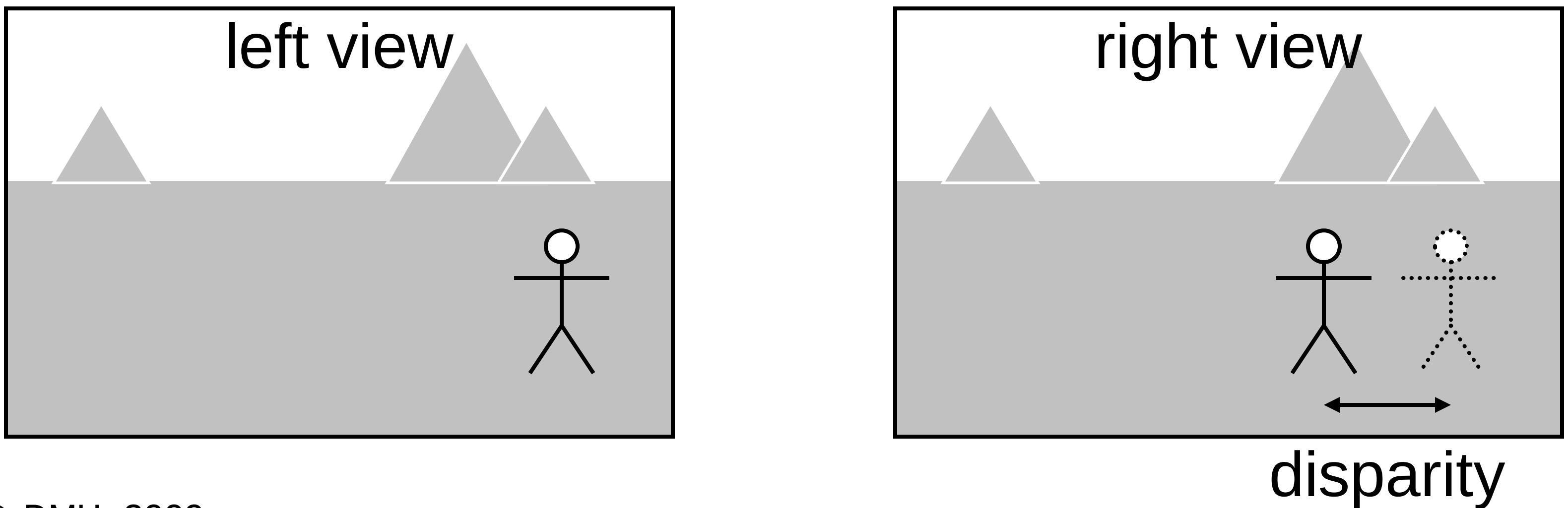


Visual Sensors

- A digital image is a collection of samples representing the visual content of the environment.
- Each individual sample is represented in the form of a pixel or picture element. Each pixel is a point on rectangular lattice with finite resolution encoding some form of intensity.
- For the image to look unbroken (continues) a minimum number of samples should be taken. The minimum sampling frequency is known as the Nyquist frequency:
  - The signal should be sampled 'at a rate at least twice as great as the highest frequency in the signal'

Stereoscopic Vision

- Viewing the world with two cameras (eyes) allows a three-dimensional representation to be formed
  - unfortunately the signal is complex and noisy
- Each camera receives a slightly different view
  - the distance between corresponding points in an image is known as the *stereo disparity*



Object Recognition

- Much research has gone into the field of object recognition (it seems so easy for us humans!), but the problem has not been solved yet
  - it seems humans use a combination of techniques
- Edge detection
  - fairly simple filter operations can detect clean edges
    - e.g. the discrete Laplace filter
  - reliable detection of all edges is much more difficult
- Area based techniques
  - connected regions of similar colour, texture or brightness probably belong to the same object

Actuators

Locomotion

Mobility Considerations

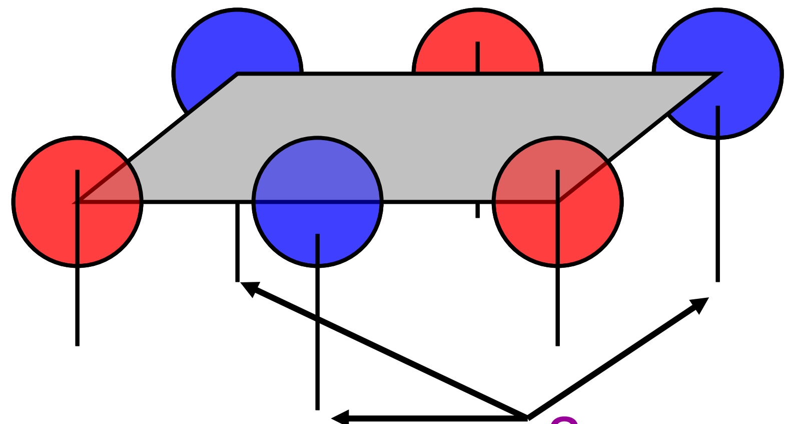
- Issues impact selection of drive
  - *manoeuvrability* ability to alter direction/speed
  - *controllability* practical and not too complex
  - *traction* sufficient to minimise slippage
  - *climbing ability* traversal of minor discontinuities, slope rate, surface type, terrain

Mobility Considerations

- Issues that impact selection of drive (cont…)
  - *stability* mustn't fall over!
  - *efficiency* power consumption reasonable
  - *maintenance* easy to maintain, reliable
  - *environmental impact* does not do damage
  - *navigation* accuracy of dead-reckoning

Legs

- Two legs seems the most familiar configuration
  - But balance is an incredibly difficult problem
  - Need very fast and supple joints to move and balance
  - Standing still is an active task (uses energy!!)
- Four legs are much easier to balance and move … are they?
- Six legs are much easier to balance and move
  - Stable when not moving
  - Can work with simple cams and rigid legs
  - Processing is much simpler!



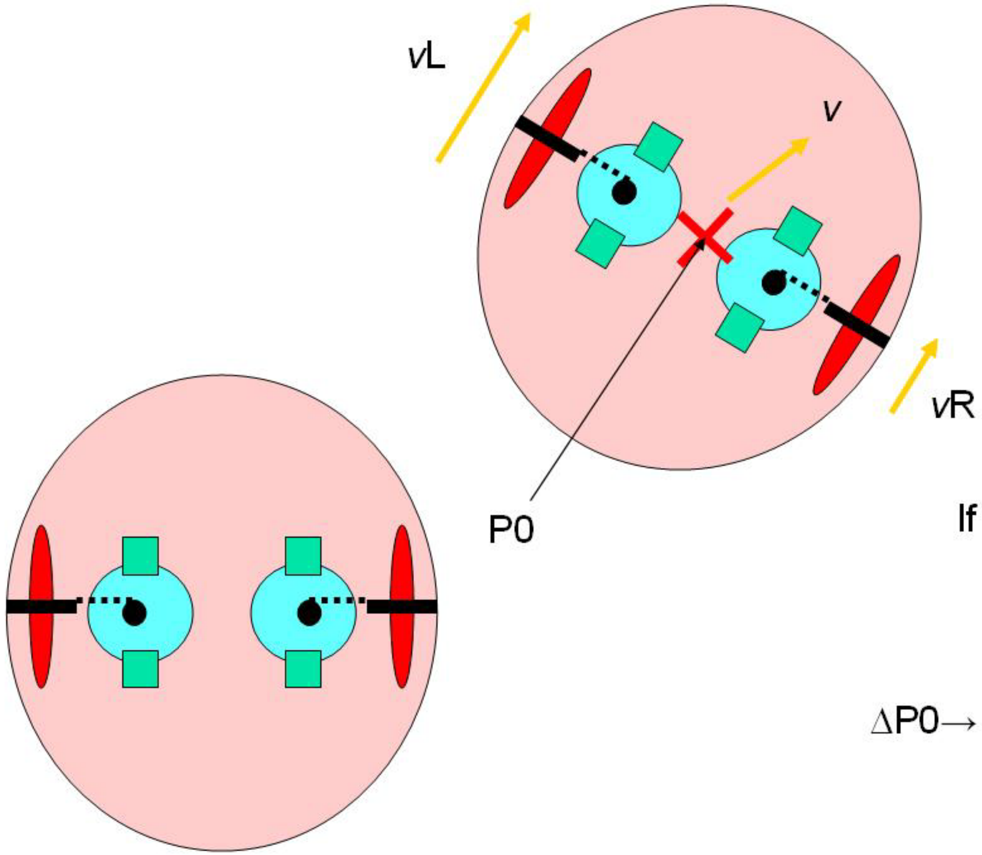
Wheels

- Again, any number of wheels is possible
  - there are many different configurations that are useful
- Two individually driven wheels on either side
  - usually with one or more *idler wheels* for balance
  - independently driven wheels allows zero *turning radius*
    - one wheel drives forwards, one wheel drives backwards
- Rear wheel drive, with front wheel steering
  - the vehicle will have a non-zero turning radius
  - for two front wheels, turning geometry is complex
  - the rear wheels need a *differential* to prevent slippage
- 4WD is possible, but it is even more complex

Exotic Wheels and Tracks

- Tracks can be used in the same way as 2 wheels
  - good for rough terrain (as compared to wheels)
  - tracks must slip to enable turns (*skid steering*)
- In *synchro drive* three or more wheels are coupled
  - drive in same direction at same rate
  - pivot in unison about their respective steering axes
  - allows body of robot to remain in the same orientation
- Tri-star wheels are composed of 3 *sub-wheels*
  - entire wheel assembly rolls over a large obstacle
- There are many other exotic wheel configurations
  - multiple-degrees-of-freedom (MDOF), e.g. Kilough

Wheels and Tracks



If $vL = -vR$:

$\Delta P0 = \{$

$|\Delta P0| = 0;$

$\Delta P0\rightarrow = |vL * \Delta t| / R\omega;$

$\}$

If $vL \neq vR$ and Δt is small:

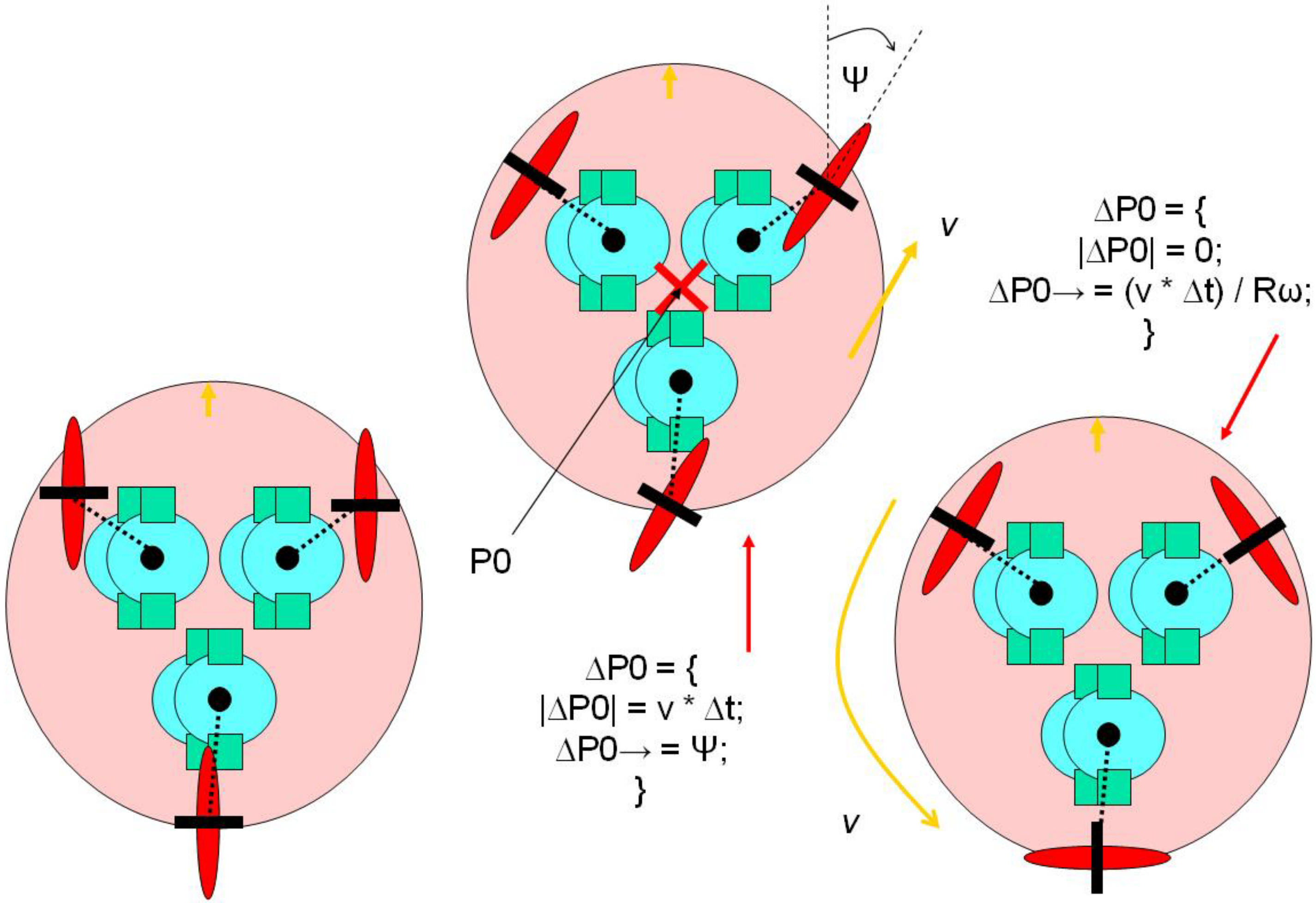
$\Delta P0 = \{$

$|\Delta P0| = |vL+vR|/2 * \Delta t;$

$\Delta P0\rightarrow = (|vL - vR|/2 * \Delta t) / R\omega;$

$\}$

Exotic Wheels and Tracks



Actuators

Manipulation

Actuator Types

- Electric
  - DC motor is most common type used in mobile robots
  - stepper motors turn a certain amount with a voltage pulse
- Pneumatic
  - operate by pumping compressed air through chambers: slow.
- Hydraulic
  - pump pressurised oil: usually too heavy, dirty and expensive to be used on mobile robots
- Shape memory alloys (SMA’s)
  - metallic alloys that deform under heat and then return to their previous shape: *used for artificial muscles*

Arms and Grippers

- *Degrees-of-freedom*
  - independently controllable components of motion
- Arms
  - convenient method to allow full movement in 3D
  - more often used in fixed robots due to power & weight
  - even more difficult to control!
    - due to extra degrees of freedom
- Grippers
  - may be very simple (two rigid arms) to pick up objects
  - may be complex device with *fingers* on end of an arm
  - probably need feedback to control grip force
    - e.g. picking up an egg!

Measuring Motion

Odometry

- If wheels are being used, then distance traveled can be calculated by measuring number of turns
  - *dead-reckoning* or *odometry* is the name given to the direct measure of distance (for navigation)
- Motor speed and timing are very inaccurate
  - measuring the number of wheel rotations is better
  - *shaft encoders*, or *rotation sensors*, measure this
  - Can be used in Mobile Robots as well as Manipulators

Odometry

- There are many different types and technologies of shaft encoder
  - Optical encoders (relative)
  - Potentiometers (absolute for each turn)
- In practice, slippage means that dead-reckoning is unreliable over all but very short distances
- And is a relative measurement at the end, so…