BLG456E
Robotics
Control

Lecture Contents:
- Open-loop vs closed-loop.
- Bang-bang control & P control.
- PID control.
- Tuning of controllers.
- Simple control law for differential drive.
- Control in context.

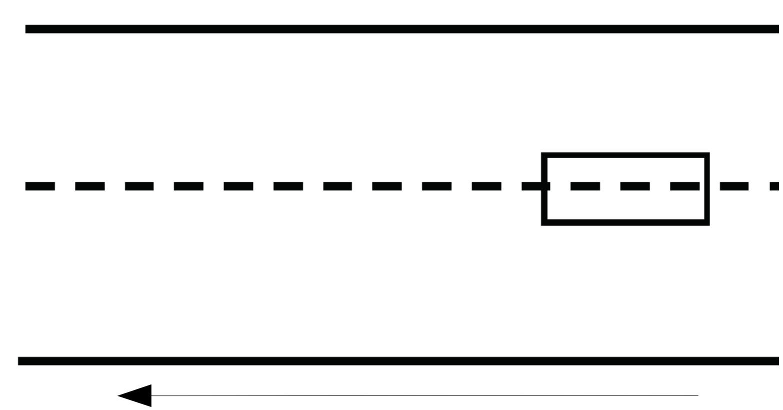
Lecturer:	Damien Jade Duff
Email:	djduff@itu.edu.tr
Office:	EEBF 2316
Schedule:	http://djduff.net/my-schedule
Coordination:	http://ninova.itu.edu.tr/Ders/4709

Low-level control

- Getting a dynamical system to follow a reference trajectory.
  - E.g.
    - Cruise controller.
    - Thermostat.
    - Wall-follower.
    - Trajectory follower.
    - Hovering controller.
    - Balancing controller.

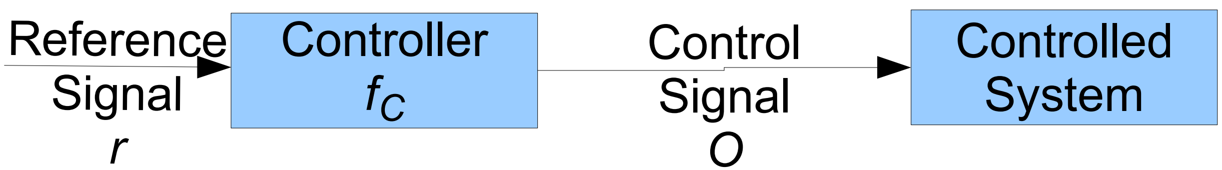
Low-level control example

- Car travelling along a road at constant velocity.
- Wants to stay in the middle.
- Can measure distance away from the middle. s_d
- Can steer. ω



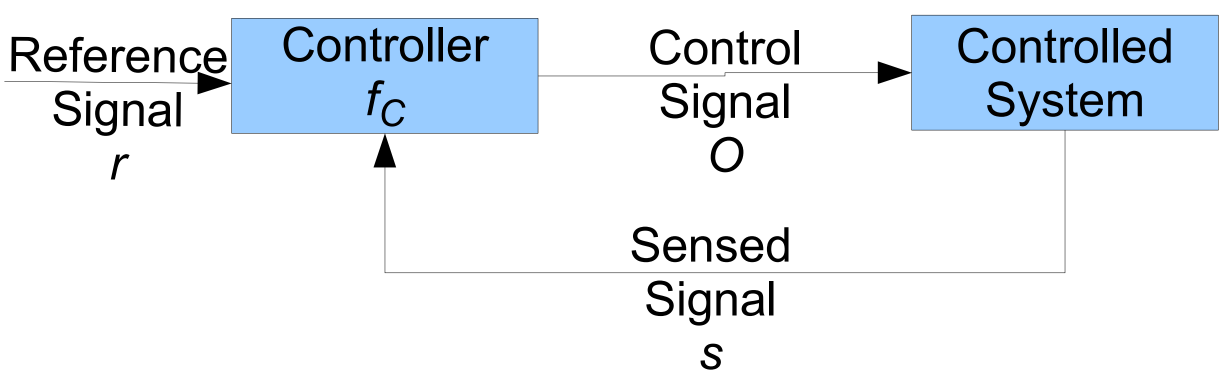
Open-loop vs closed-loop control

- Open-loop control:
    - *No feedback incorporated.*



$$O = f_C(t, r)$$

- Closed-loop control:
    - *Feedback incorporated.*

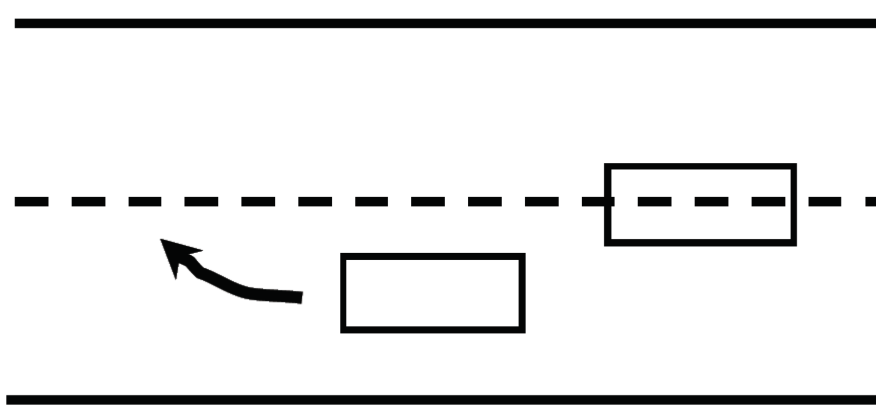


$$O = f_C(t, r, s)$$

t = time

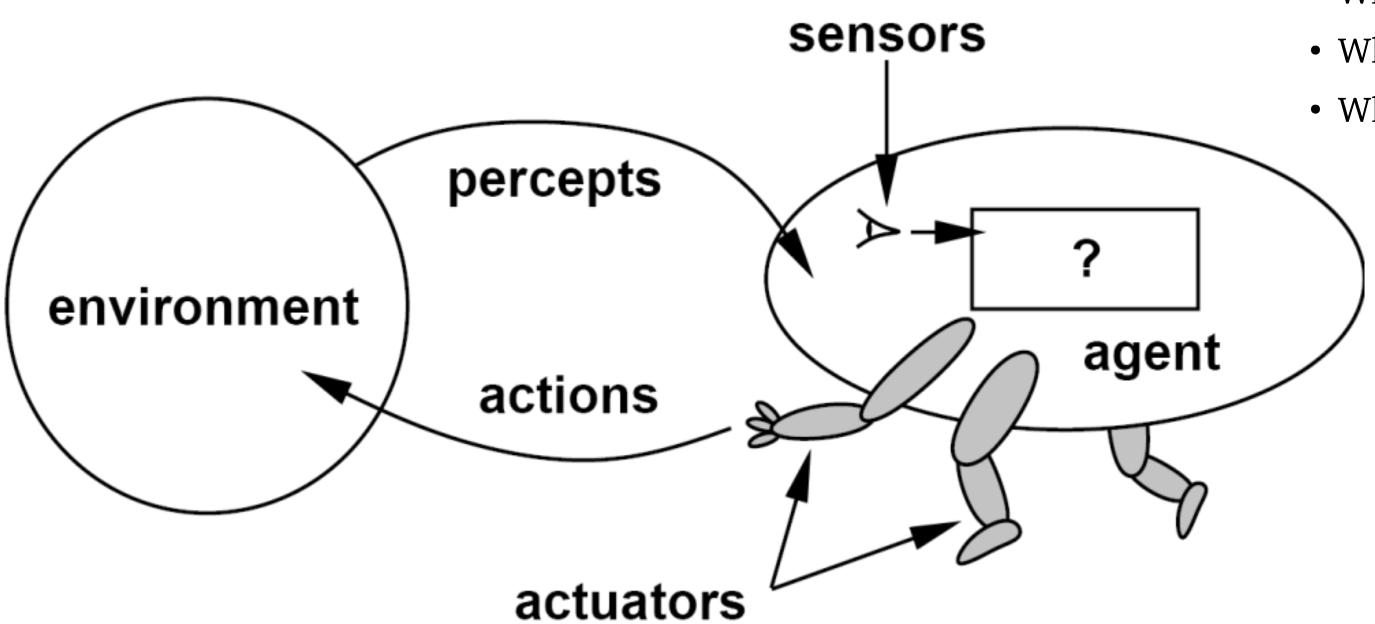
Open-loop vs closed-loop control: car example

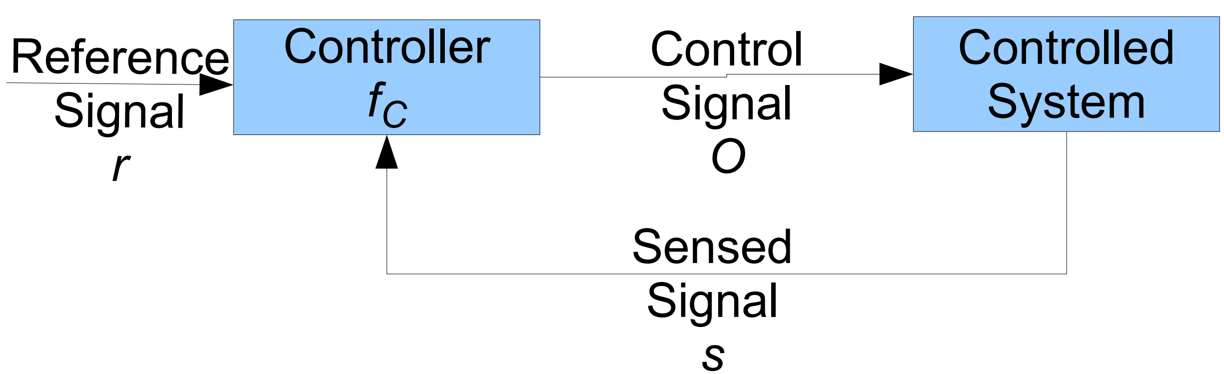
- Open loop control: $\omega = O_o = 0$
  - Keep the wheel straight.
- Closed-loop control: $\omega = O_f = f_C(s_d)$
  - Steer depending on distance from centre.



Closed-loop control vs. agents

- Where is the controller function f_c?
- Where is the controlled system?
- Where is the control signal?
- Where is the sensed signal?





$$O = f_C(t, r, s)$$

- Where are the percepts?
- Where are the actions?
- Where is the agent?
- Where is the environment?

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Two basic kinds of feedback control

- Bang-bang control:

  Switch between modes based on thresholds.

$$O_f = f_{bb}(s) = \begin{cases} o_1 & \text{if } s > s_{thresh} \\ o_2 & \text{otherwise} \end{cases}$$

- Proportional (P) control:

  Alter control signal proportional to error.

$$O_f = f_p(s) = -k_p s \qquad (\ k_p \text{ is } \underline{\text{gain}}\ )$$

Error = difference between reference and sensed state.

Bang-bang control: car example

$$\omega = O_f = f_{bb}(s_d) = \begin{cases} -25^\circ \text{ if } s_d > 0.0. \\ 25^\circ \text{ otherwise.} \end{cases}$$

- Car too far left?
  - Bang! Turn right!
- Car too far right?
  - Bang! Turn left!

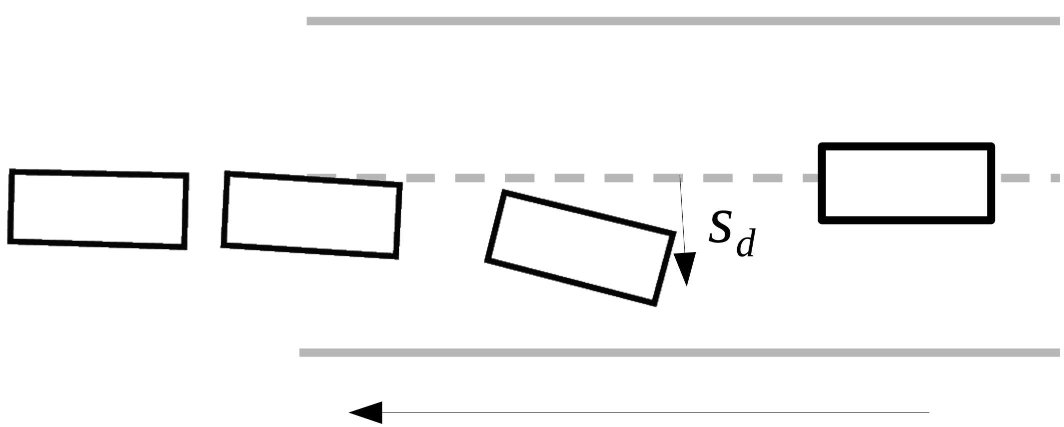
Bang-bang control evaluation

- Good for boiling an egg (optimal).
- Not good for driving a car.
  - Car needs smooth control.

Proportional (P) control: car example

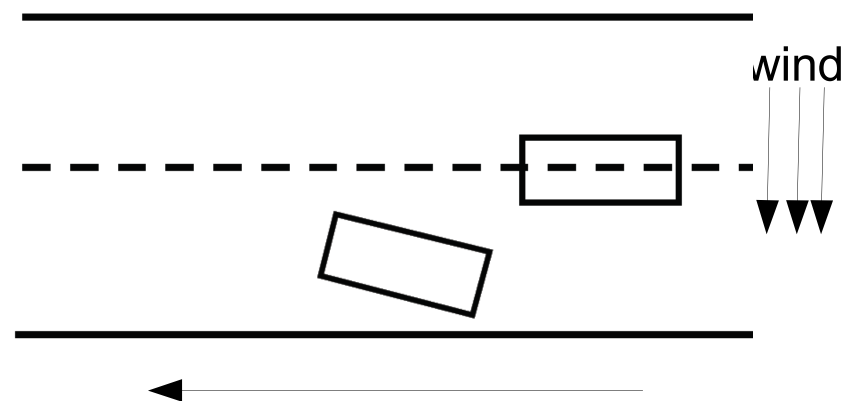
$$\omega = O_f = f_p(s_d) = -10\, s_v$$

Degree of steer is proportional to distance from centre.



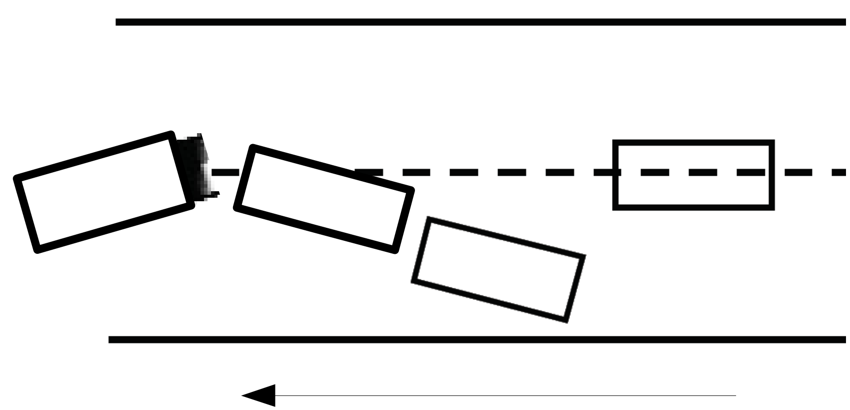
Problems with P control

1. Steady-state error (e.g. strong side-wind).



   ➔ Solution: PI control.

2. Oscillations & overshooting.



   ➔ Solution: PD control.
   (provides damping)

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PD, PI and PID control

- <u>PI control:</u> Output signal proportional to:
  - Error (P).
  - Time-integral of error (I).

$$O_f = f_{pi}(s) = -k_p s - k_i \int_t s$$

- <u>PD control:</u> Output signal proportional to:
  - Error (P).
  - Time-derivative of error (D).

$$O_f = f_{pd}(s) = -k_p s - k_d \frac{ds}{dt}$$

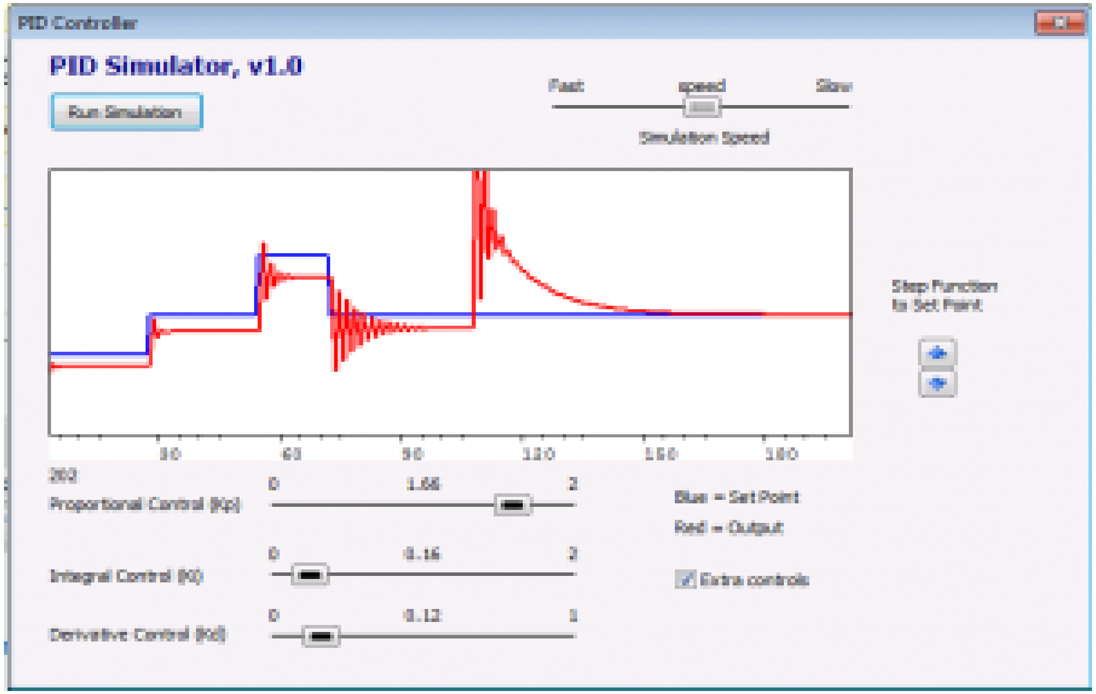
- <u>PID control:</u> Output signal proportional to:
  - Error (P).
  - Time-integral of error (I).
  - Time-derivative of error (D).

$$O_f = f_{pid}(s) = -k_p s - k_i \int_t s - k_d \frac{ds}{dt}$$

Control demonstration

- Available from

  http://blog.analogmachine.org/2012/02/04/pid-control-demonstration/



*(works with **wine** on linux, mostly)*

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Tuning controllers (Ziegler-Nichols method)

- Choice of gains important: k_p, k_i, k_d
- Ziegler-Nichols method:
  - Set all gains to 0.
  - Increase k_p until oscillation.
    - Oscillating k_p is k_c.
    - Period of oscillation is T_C.
  - Set gains from this table:

!

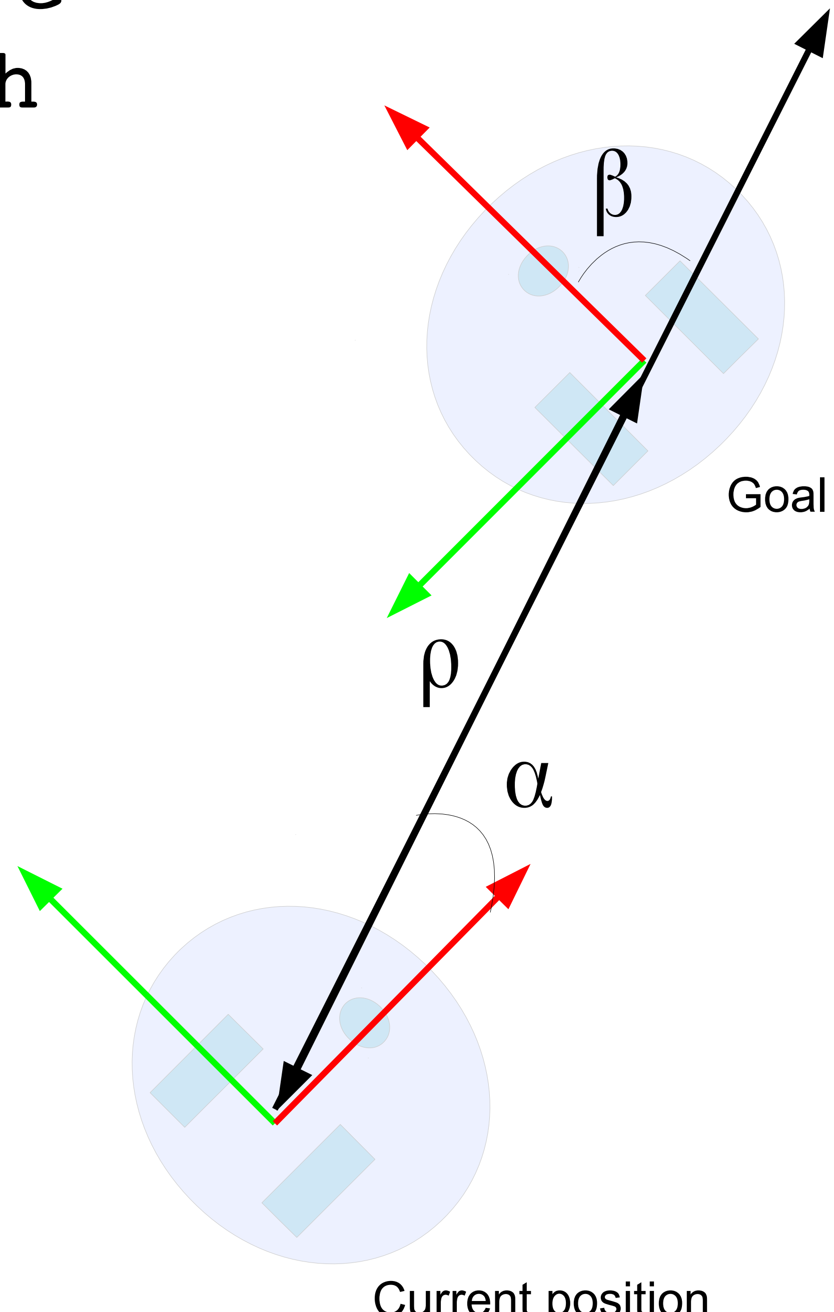
	k_p	k_i	k_d
P controller	$0.5k_c$	0	0
PI controller	$0.45k_c$	$1.2k_p/T_C$	0
PID controller	$0.5k_c$	$2k_p/T_C$	$k_pT_C/8$

Differential-drive pose control with goal-centred coordinates

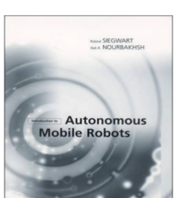
A simple control law:

$$\dot{x}_r = -k_\rho \rho$$

$$\dot{\theta}_r = -k_\alpha \alpha - k_\beta \beta$$



Question: Is this P control,
PI control, PD control, or PID control?



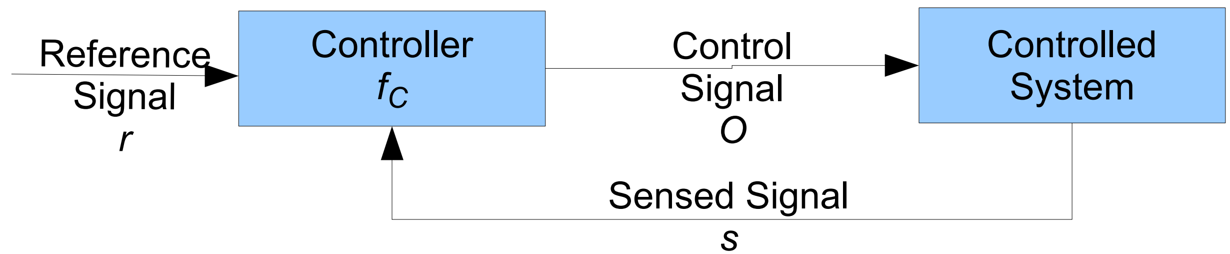
See Siegwart & Nourbakhsh section 3.6 for more details.

What low-level control is good for

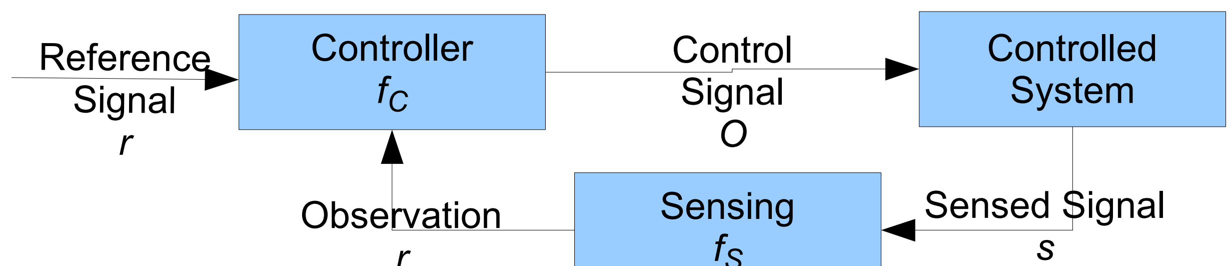
- Excellent understanding of simple system behaviour.
- Complex goals not so well understood.

With more detail: sensing, inference.

- Controller:



- With sensing:



- With inference: