Cyber-Physical Systems Challenge of the 21st Century

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Quick History

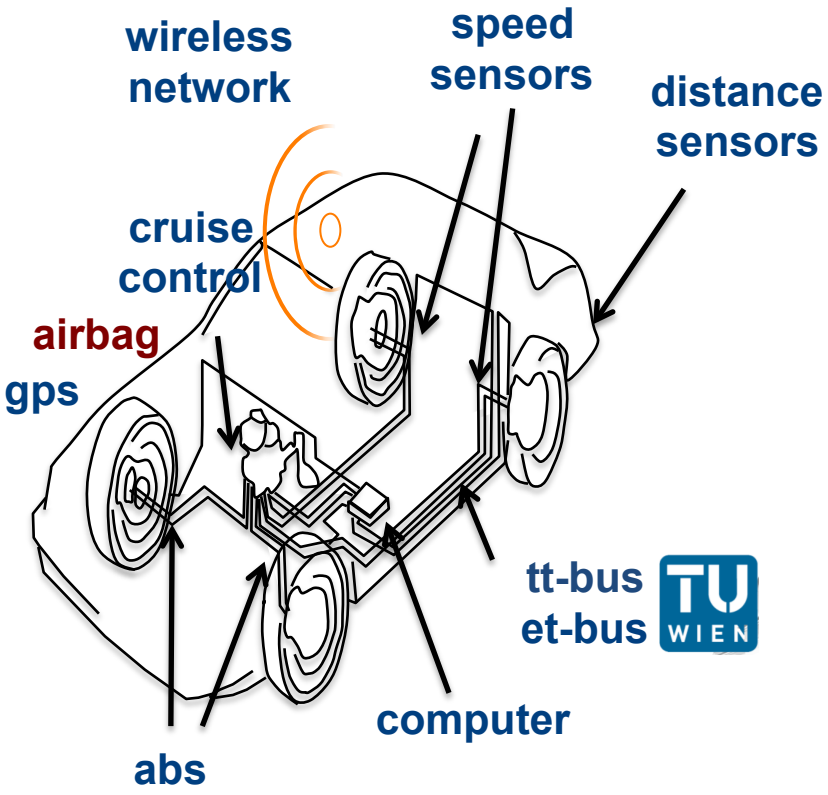
Embedded Systems
1980: e.g. airbag

Quick History

> 40 processors, 60 sensors, 40 actuators
> 100 million lines of code controlling them

Networked Embedded Systems
1990: e.g. car

Embedded Systems
1980: e.g. airbag

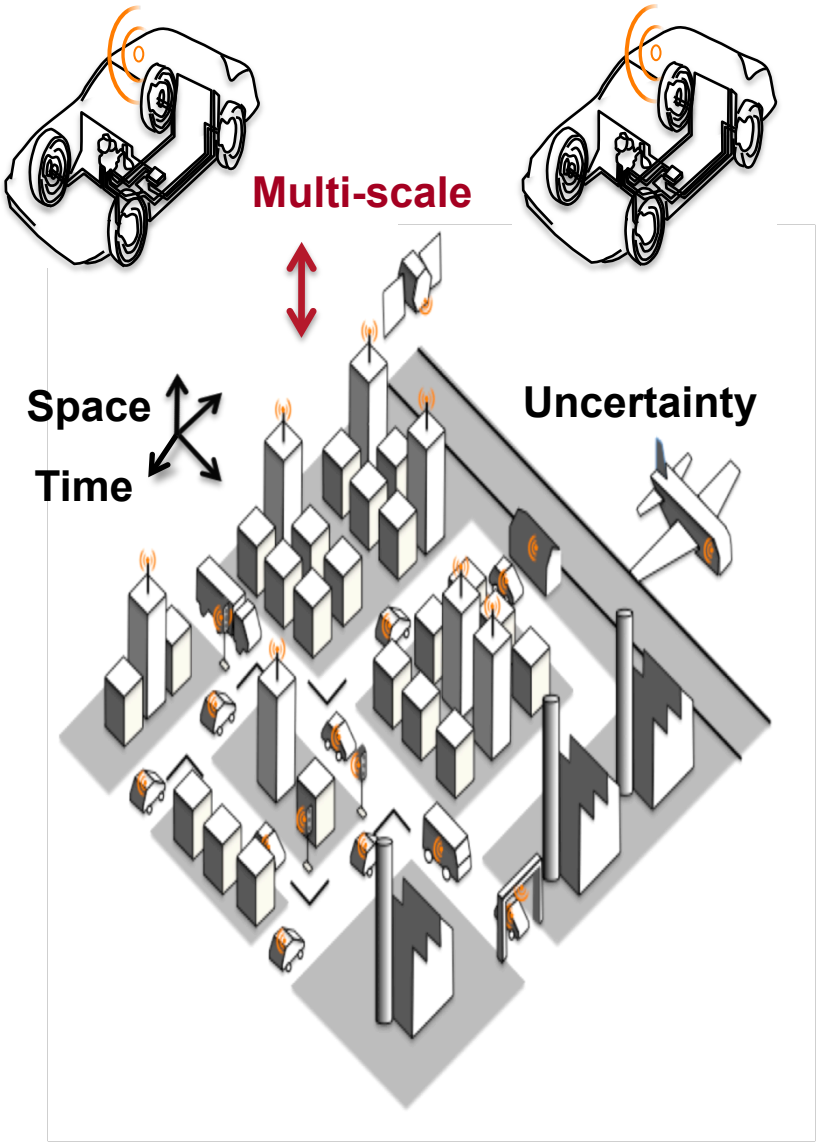


Quick History

Cyber-Physical Systems
2010: e.g. smart mobility

Networked Embedded Systems
1990: e.g. car

Embedded Systems
1980: e.g. airbag



CPS Wake-Up Call

2008: NSF and US-Scientists send CPS-Manifesto to

- **The president** of the US
- **President's Council** of Advisors on Science and Technology
- **NSF program takes off** in February 2009 within the US

2012: Acatech and DE-Scientists send CPS-Manifesto to

- **Germany's** Federal Ministry of Education and Research
- **Program takes off** in 2013 in Germany
- **H2020 program takes off** in 2014 within the EU

It is high time for a Big-Push in Austria, too!

CPS Week 2016

HSCC ICCPS IPSN RTAS

April 12-14, 2016
(Workshop & Tutorials: April 11, 2016)

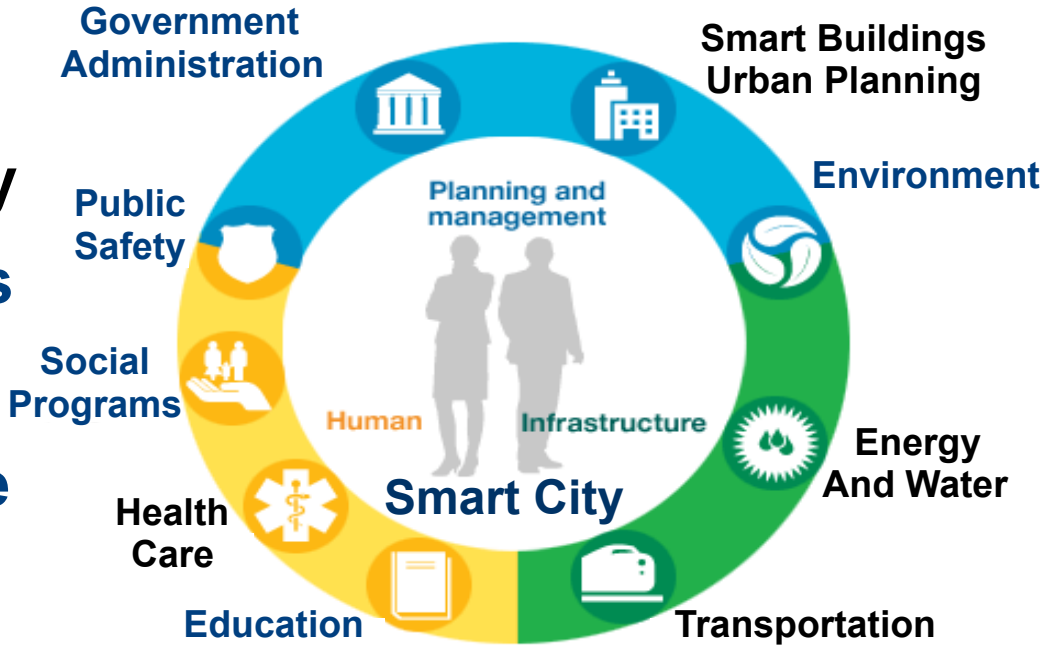
http://cpsweek2016.ocg.at


RV'15
http://rv2015.conf.tuwien.ac.at/

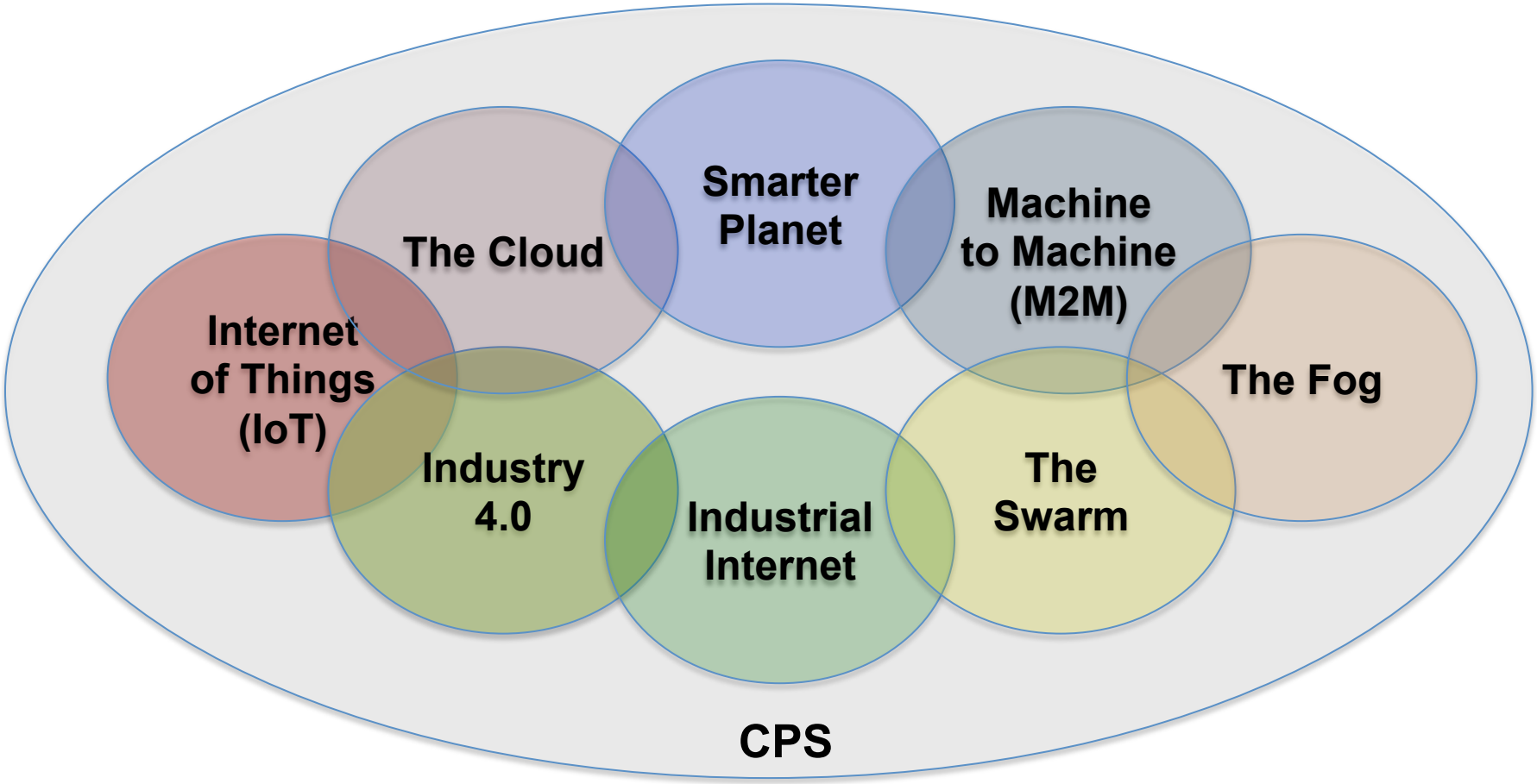
Where Are We Now?

What are the Grand Challenges?

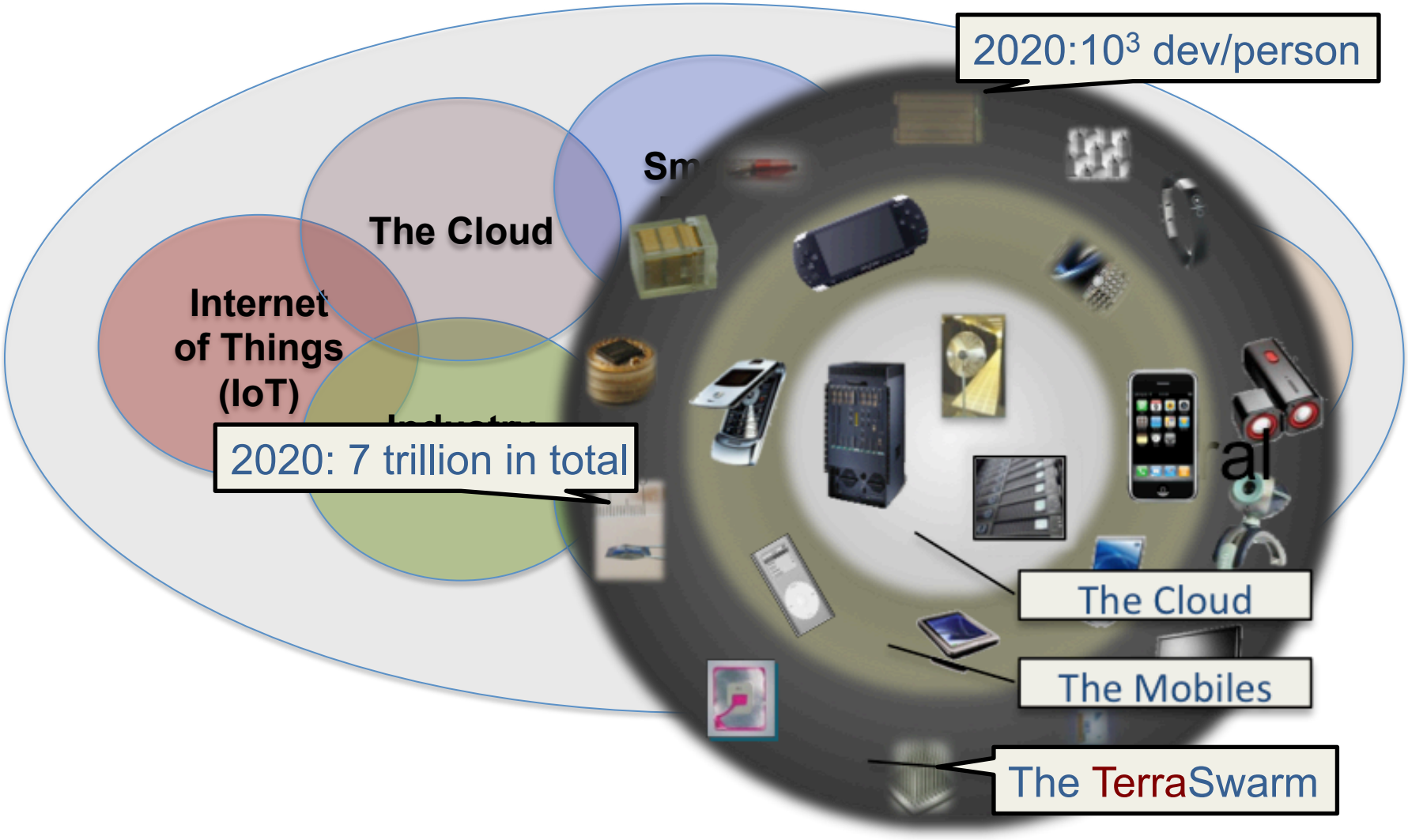
- Zero traffic-fatalities
- Blackout-free electricity
- Energy-aware buildings
- On-the-fly production
- Everywhere health-care
- Max-yield agriculture



The CPS Ecosystem



The CPS Ecosystem



What are the Technical Challenges?

Mathematics

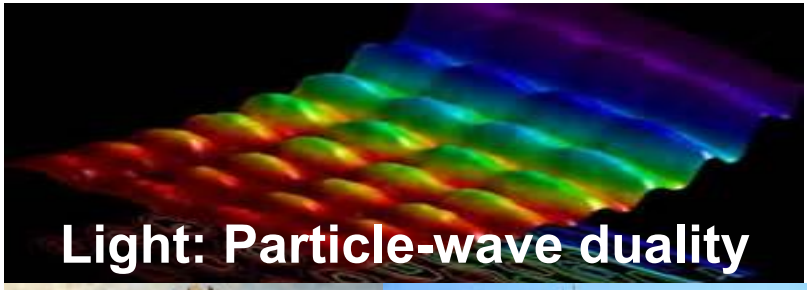
- Discrete-continuous
- Very different math

Architecture

- Huge complexity
- CPS-OS platform

Spacetime

- Various scales of ST
- ST-aware programs



What are the Technical Challenges?

Uncertainty

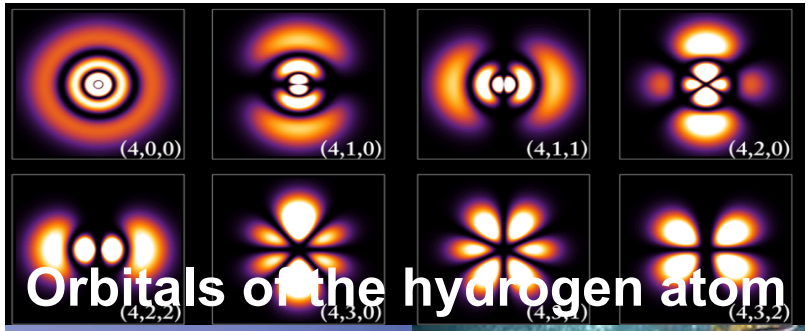
- Partial knowledge
- Limited resources

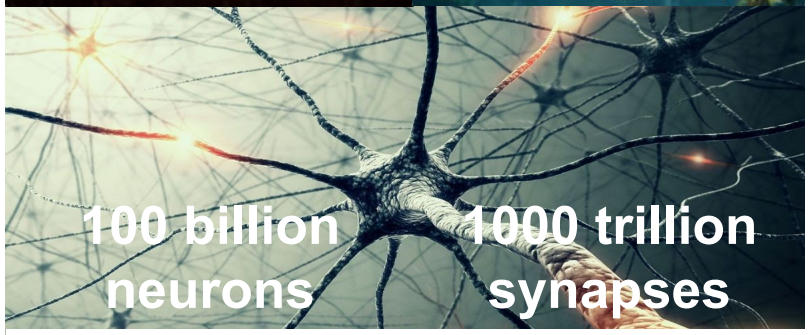
Safety

- Safety is in big no
- Emergent behavior

Smartness

- Adapting is in big no
- Neural circuits





What About Education?

Recent past (1980-2010s)

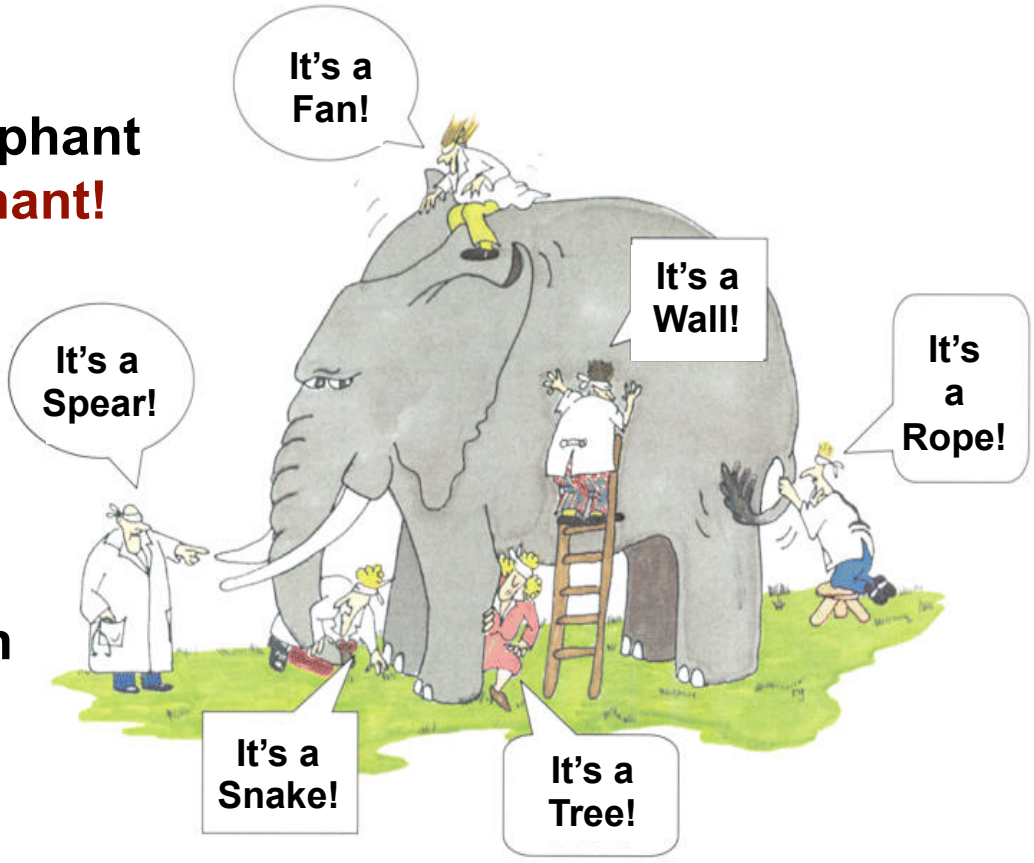
- Blind man assessing an elephant
- Blind man building an elephant!

What about now?

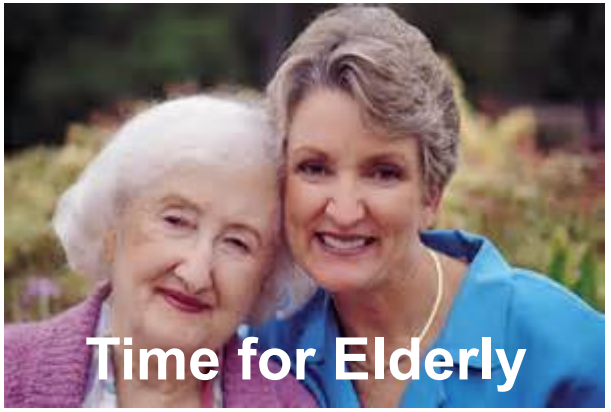
- Age of system building!
- Engineering converges

Back in the future (1950s)

- Computation: von Neumann
- Sensing/inference: Wiener
- Actuation/Control: Kalman
- Communication: Shannon

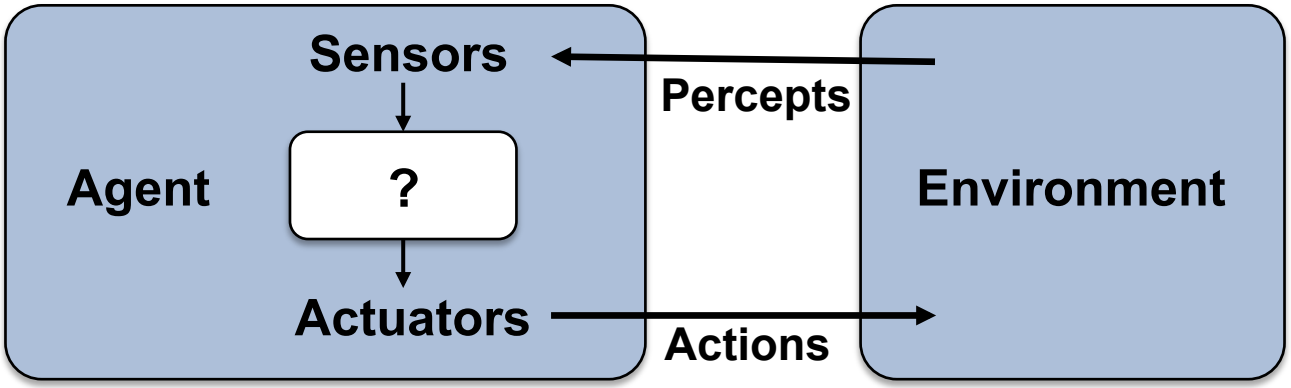


What is in Store for Us?




CPS Group

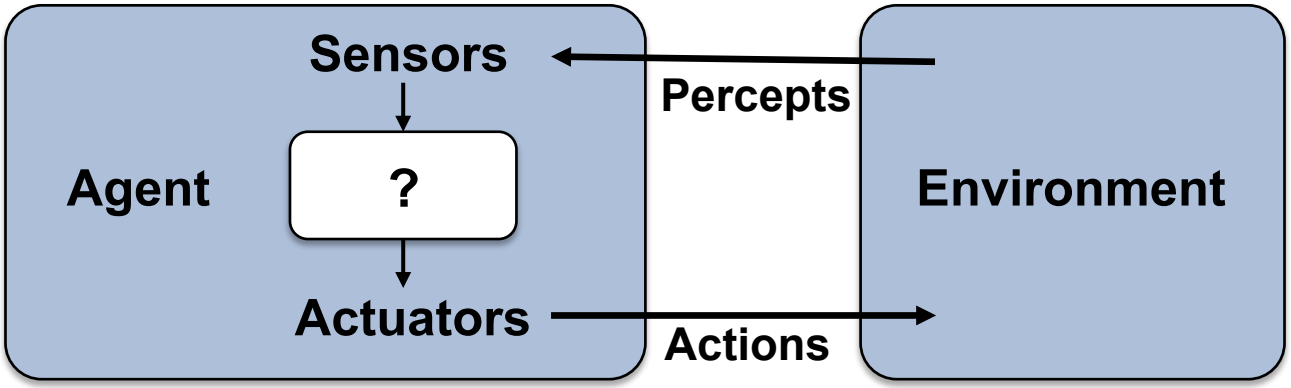
Acting Rationally



Computer Agent Latin agere = doing

- **Operates autonomously and persists** over long time
- **Perceives, acts upon and adapts** to its environment
- **Creates and pursues** its own goals

Acting Rationally

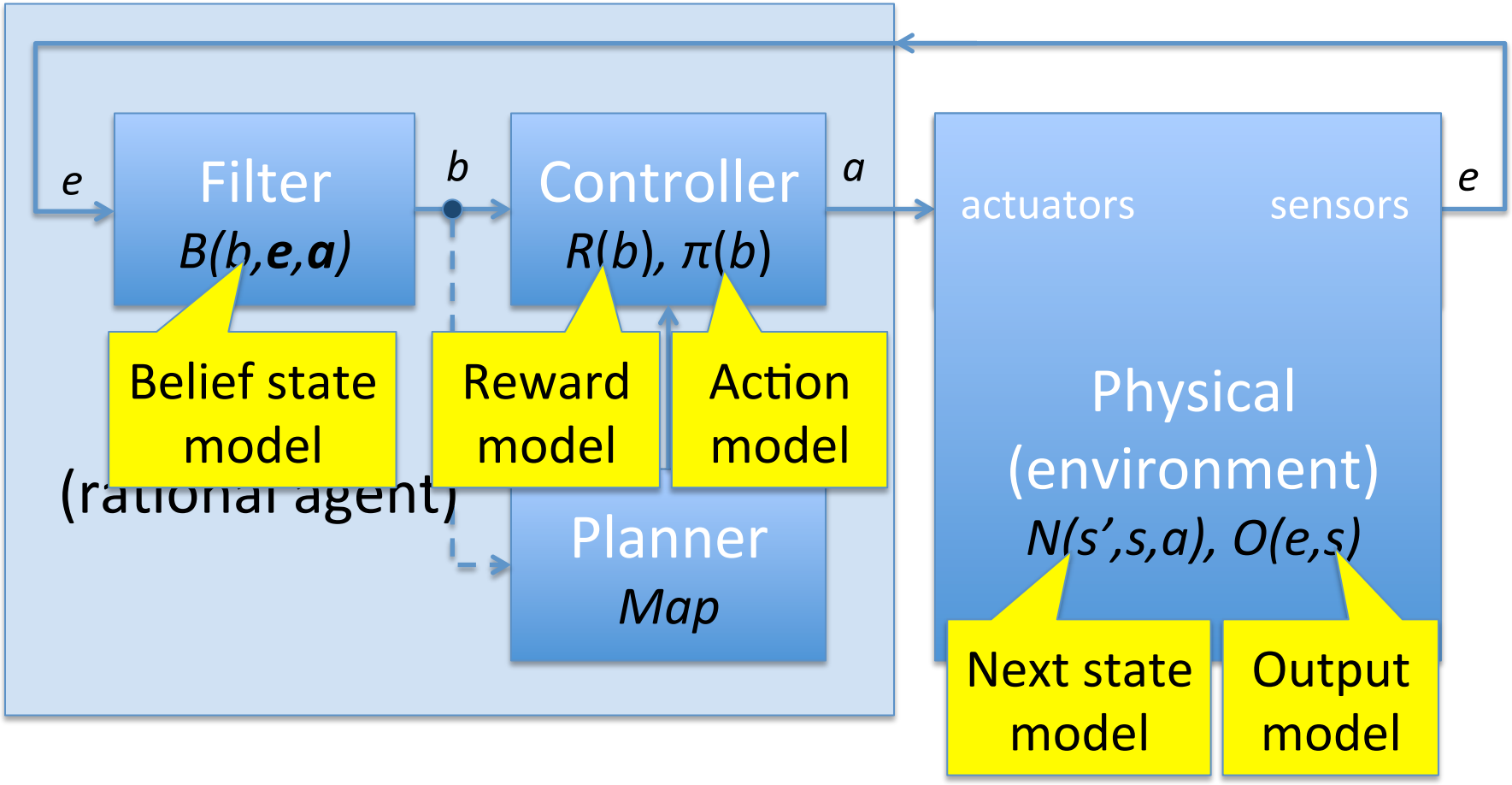


Rational Agent Extension of Computer Agent

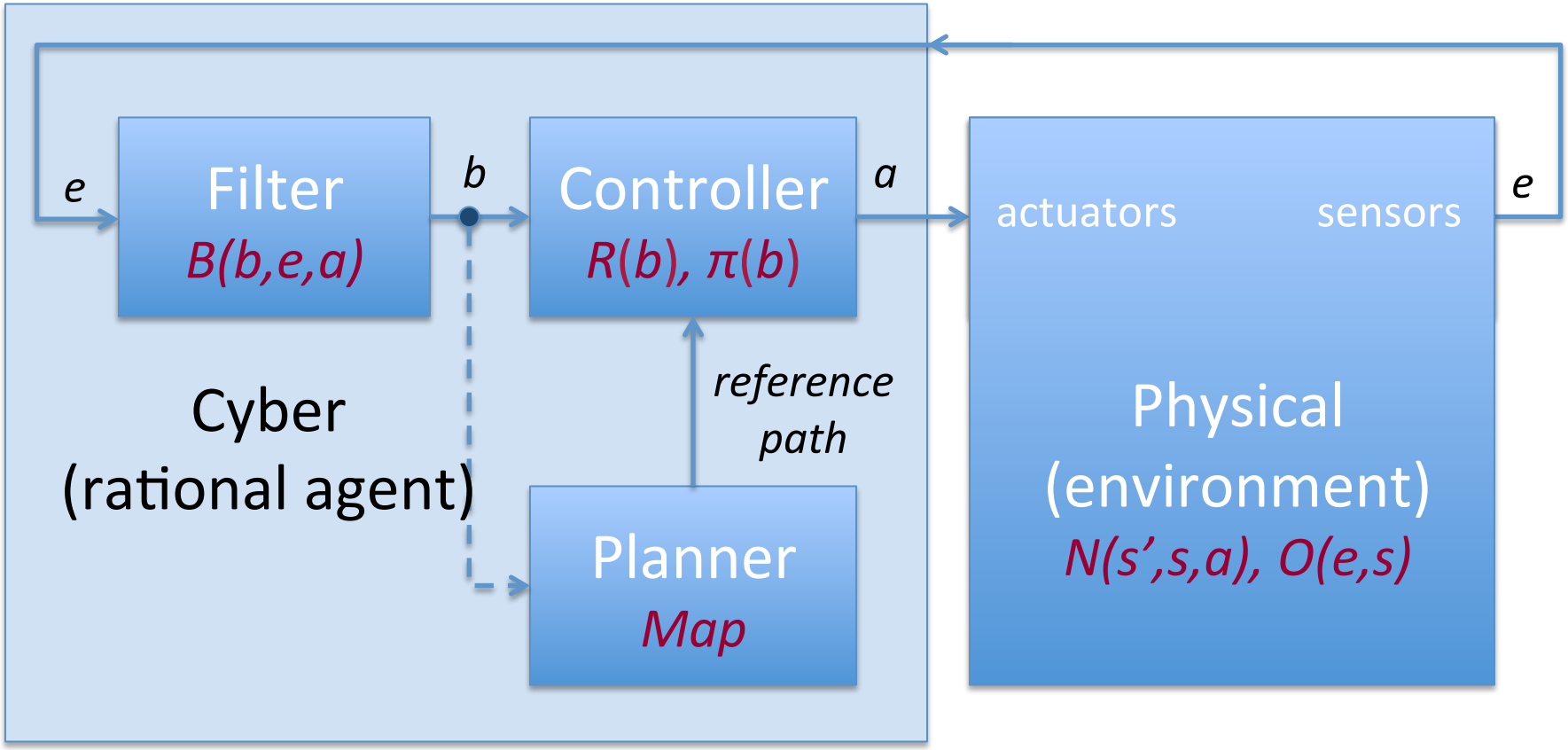
- Acts so as to achieve the best outcome, and when
- There is uncertainty, the best expected outcome

In our classes: Smart = Rational !

CPS as a Rational Agent

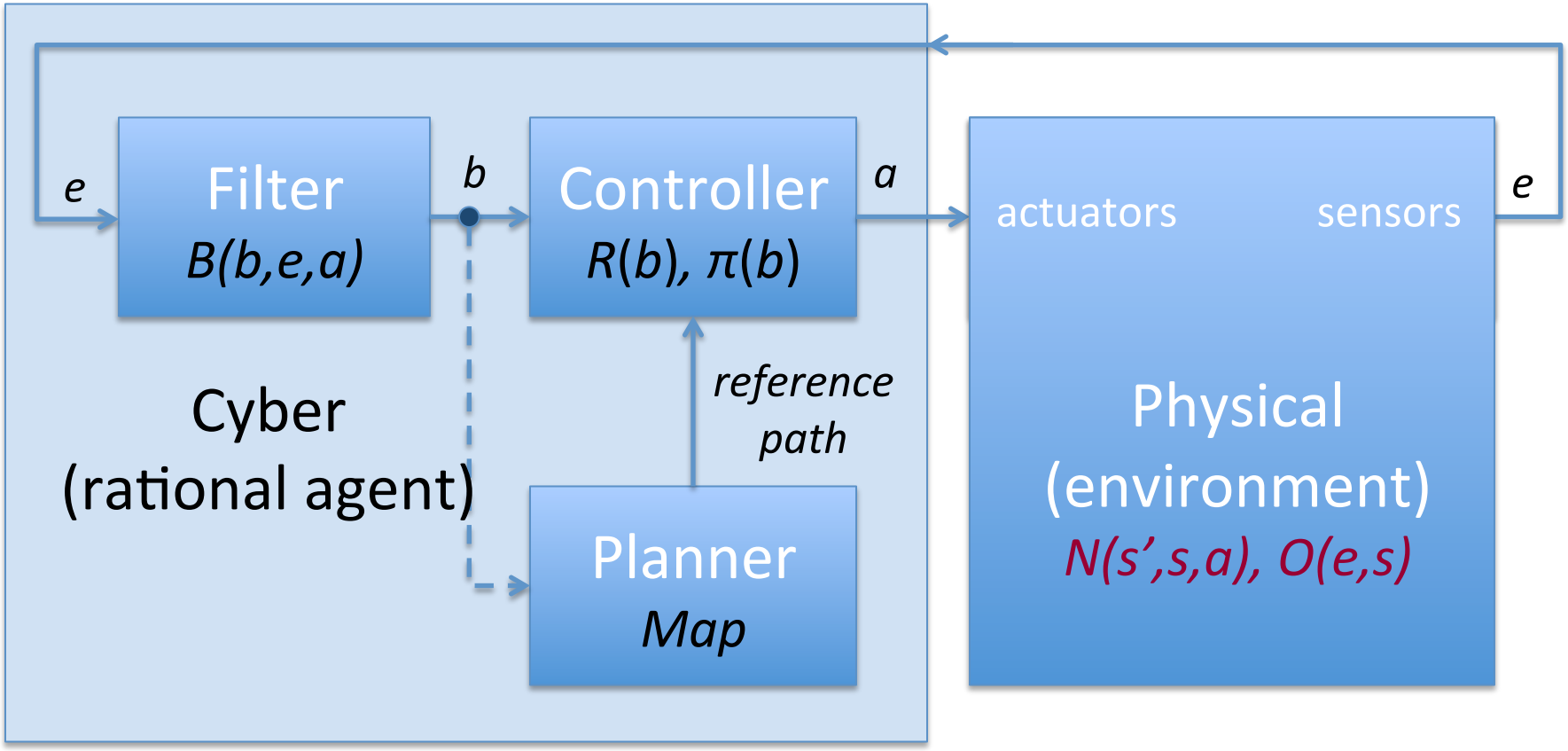


CPS as a Rational Agent: Modeling



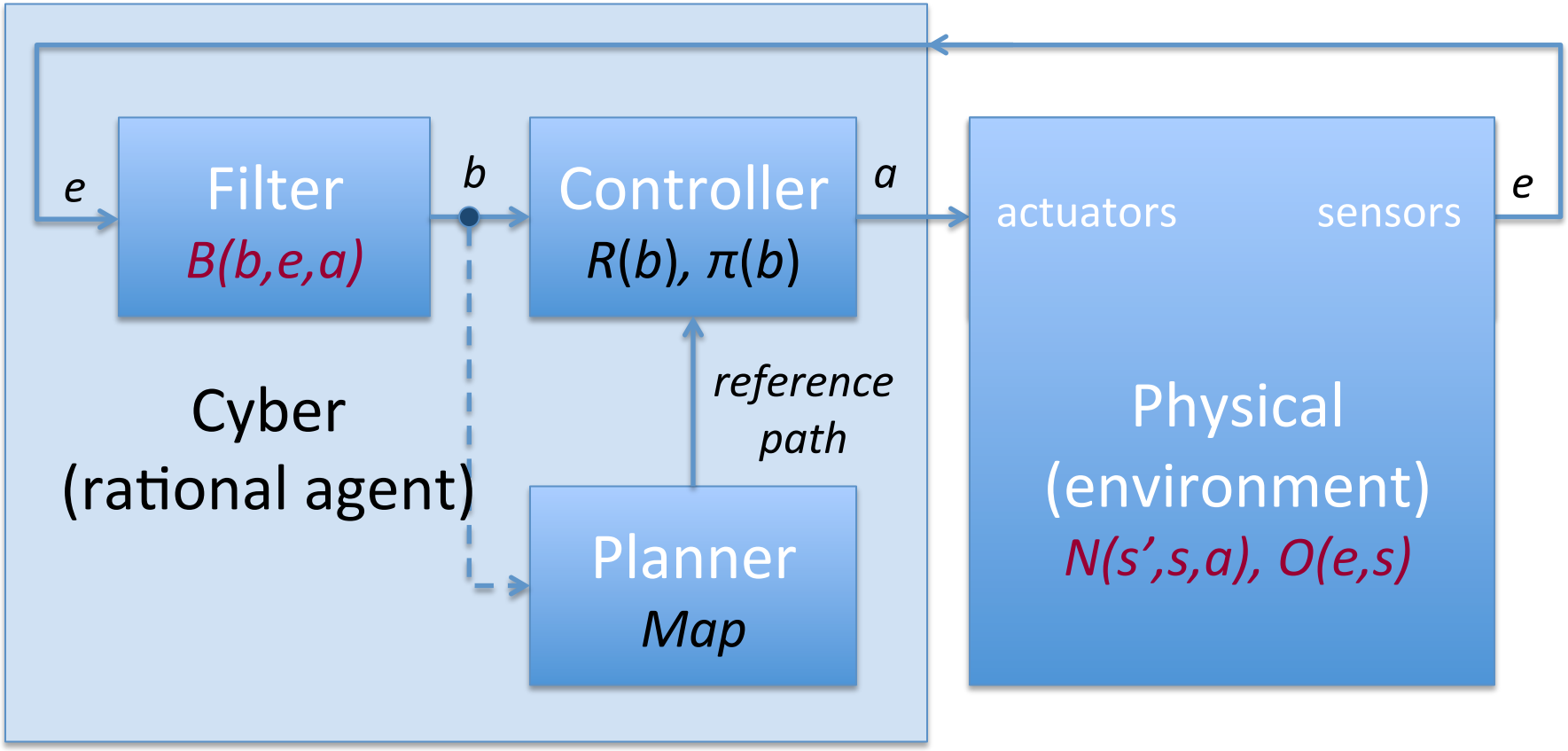
What mathematical form have all the models above?

CPS as a Rational Agent: Learning



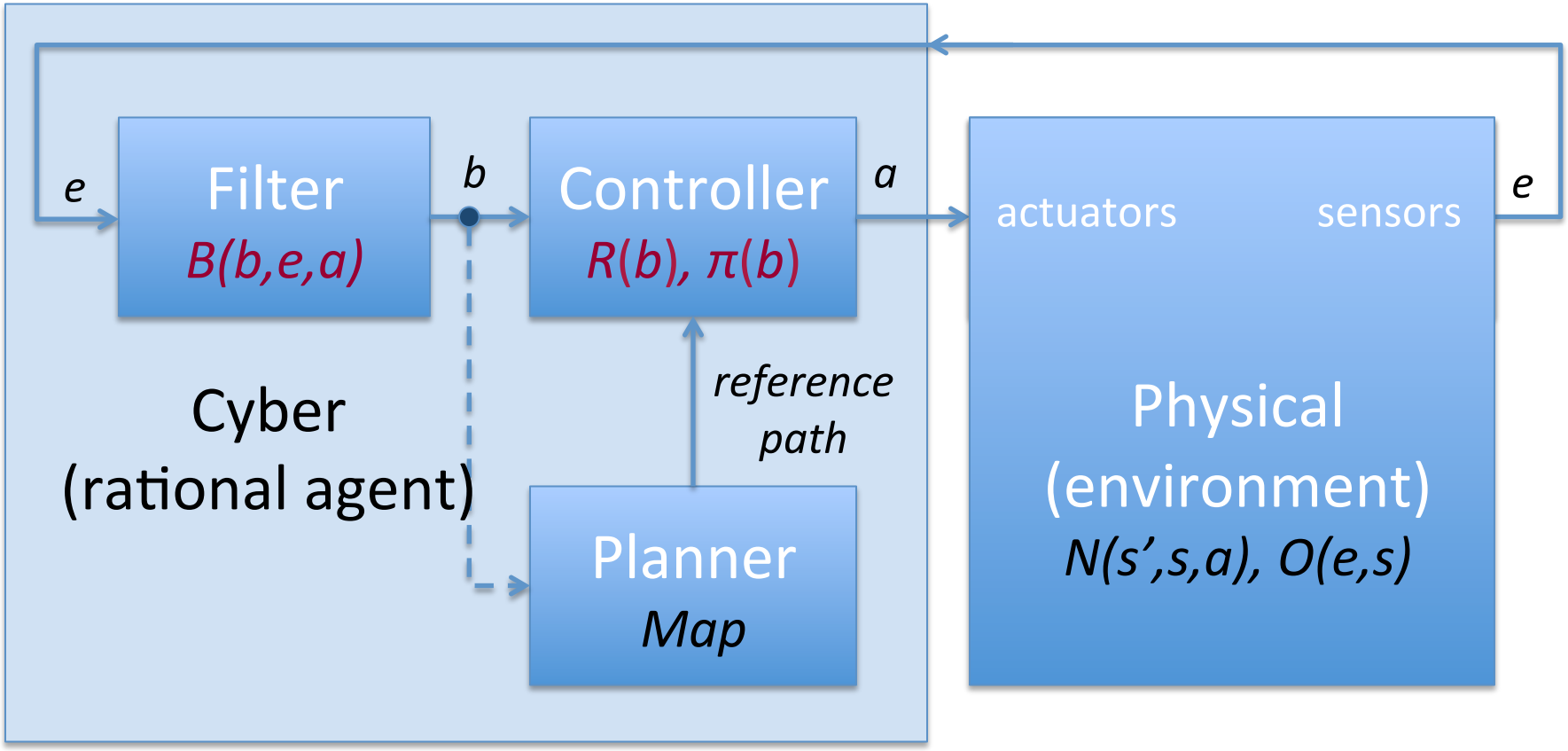
Learn next-state/output models from input/output traces.

CPS as a Rational Agent: State Estimation



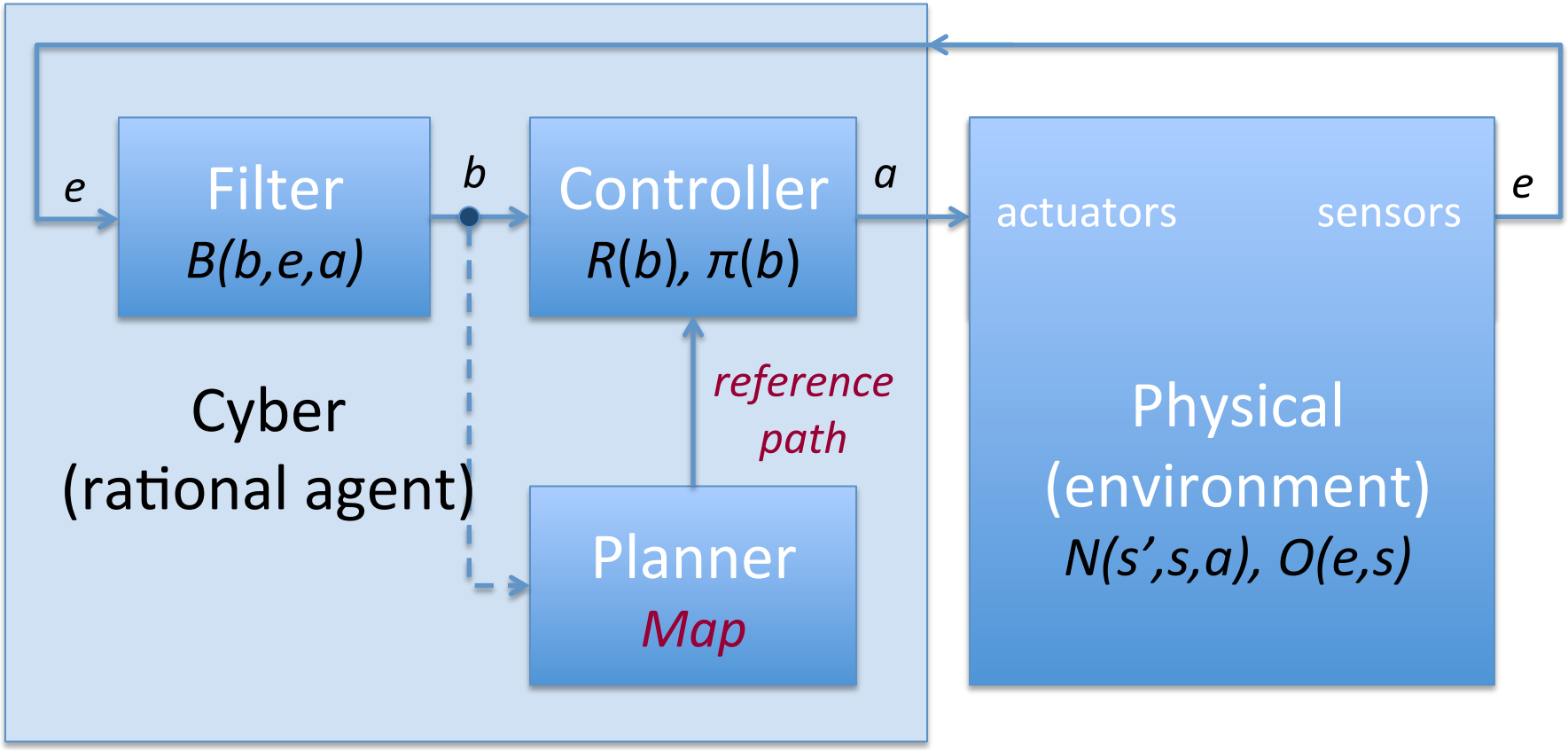
Synthesize belief state from next-state/output models.

CPS as a Rational Agent: Optimal Control



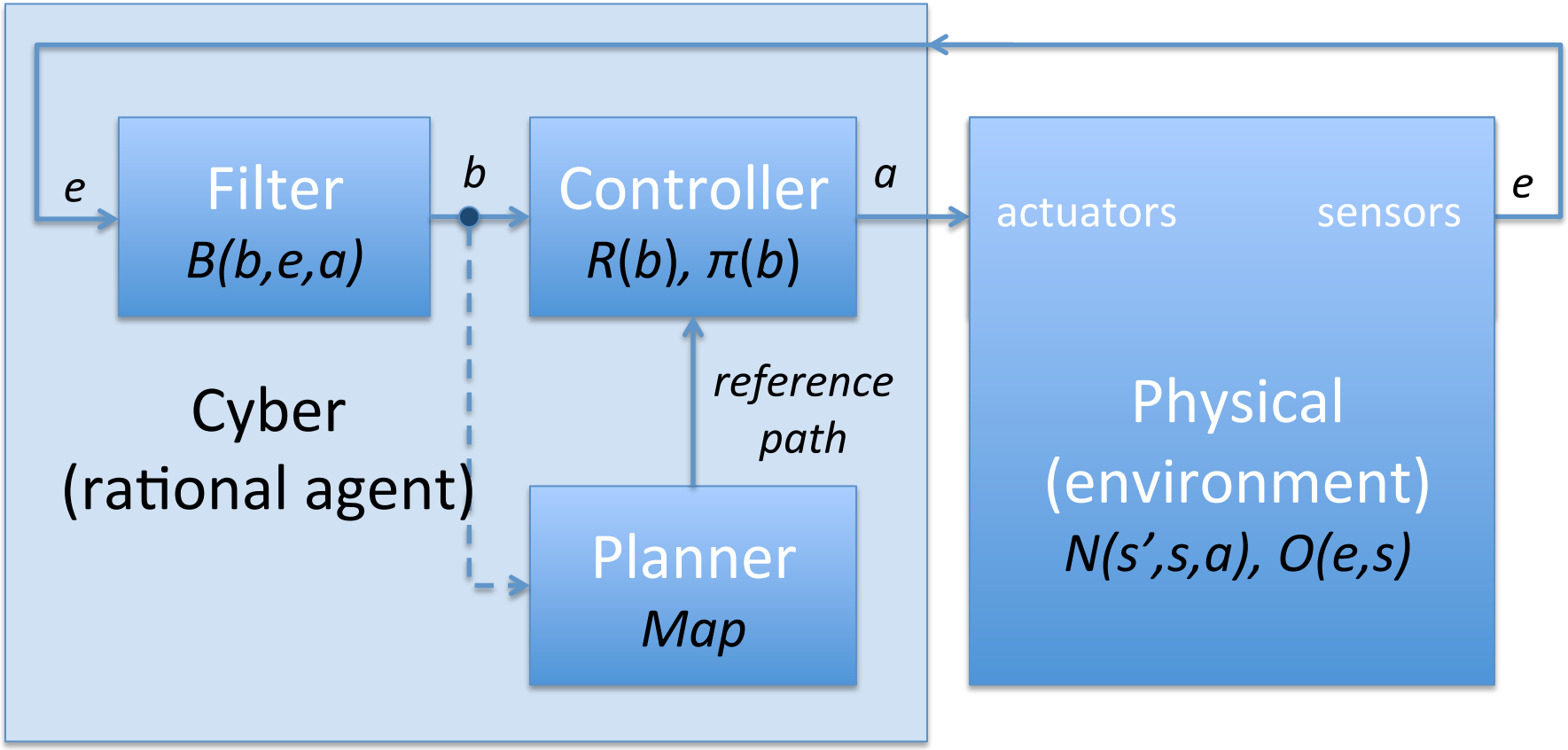
Synthesize controller from belief-state and reward models.

CPS as a Rational Agent: Planning



Synthesize the reference path from the Map.

CPS as a Rational Agent: Courses



How is uncertainty expressed mathematically?

- **Nondeterminism (logical approach):** **Hybrid Systems**
- **Probability (stochastic approach):** **CPS Eng., Mobile Robotics.**

Thinking Rationally

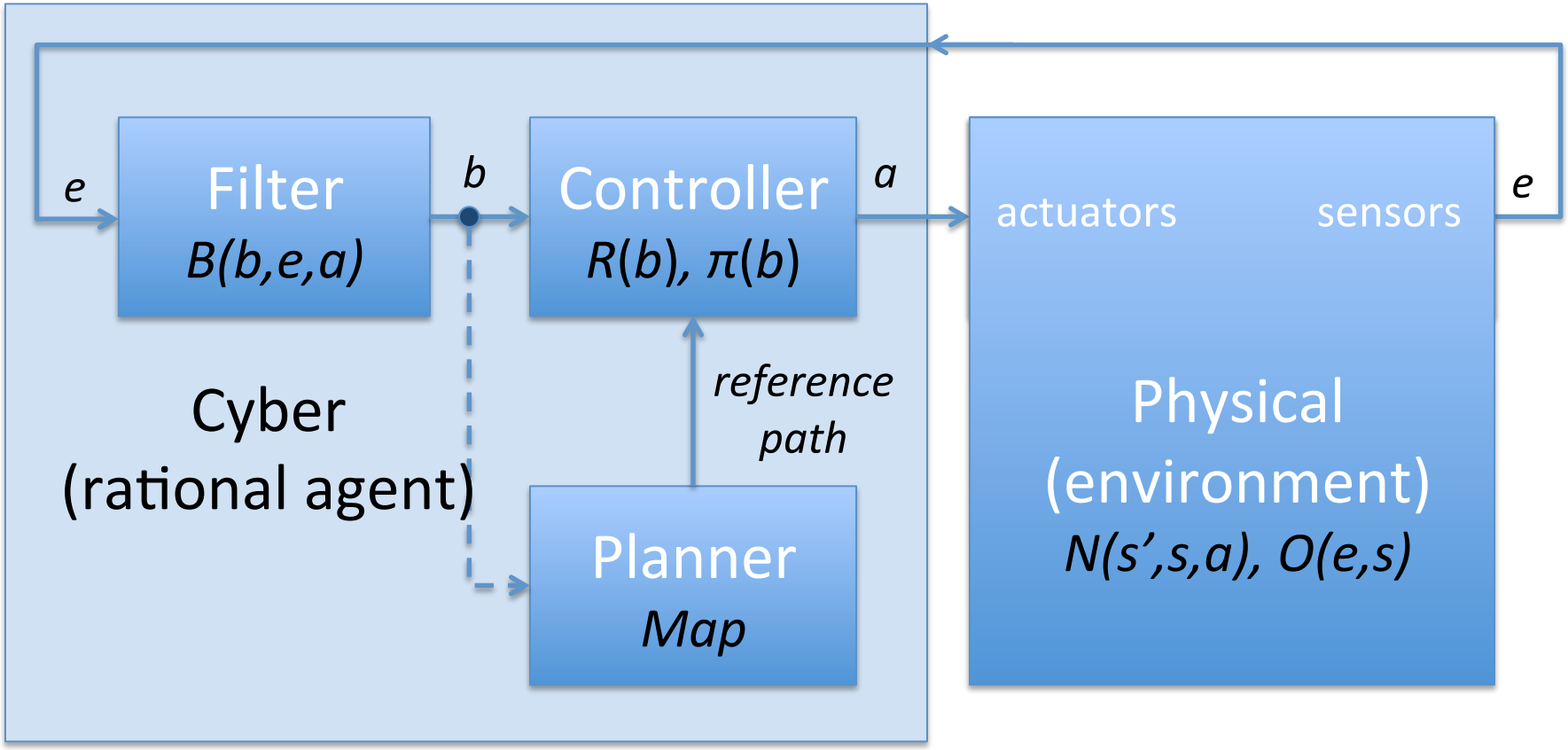
The syllogism of Greek philosopher Aristotle (nondet.)

- **Pattern for right thinking:** **Always yield correct conclusions**
- **Main pattern:** $A \wedge (A \rightarrow B) = A \wedge B = B \wedge (B \rightarrow A)$
- **Problem:** **World is not black and white (qualitative)**

The extension of syllogisms to Bayes' rule (probab.)

- **Main pattern:** $P(A)\ P(B \mid A) = P(A \wedge B) = P(B)\ P(A \mid B)$
- **Advantage:** **Shades of gray (quantitative)**

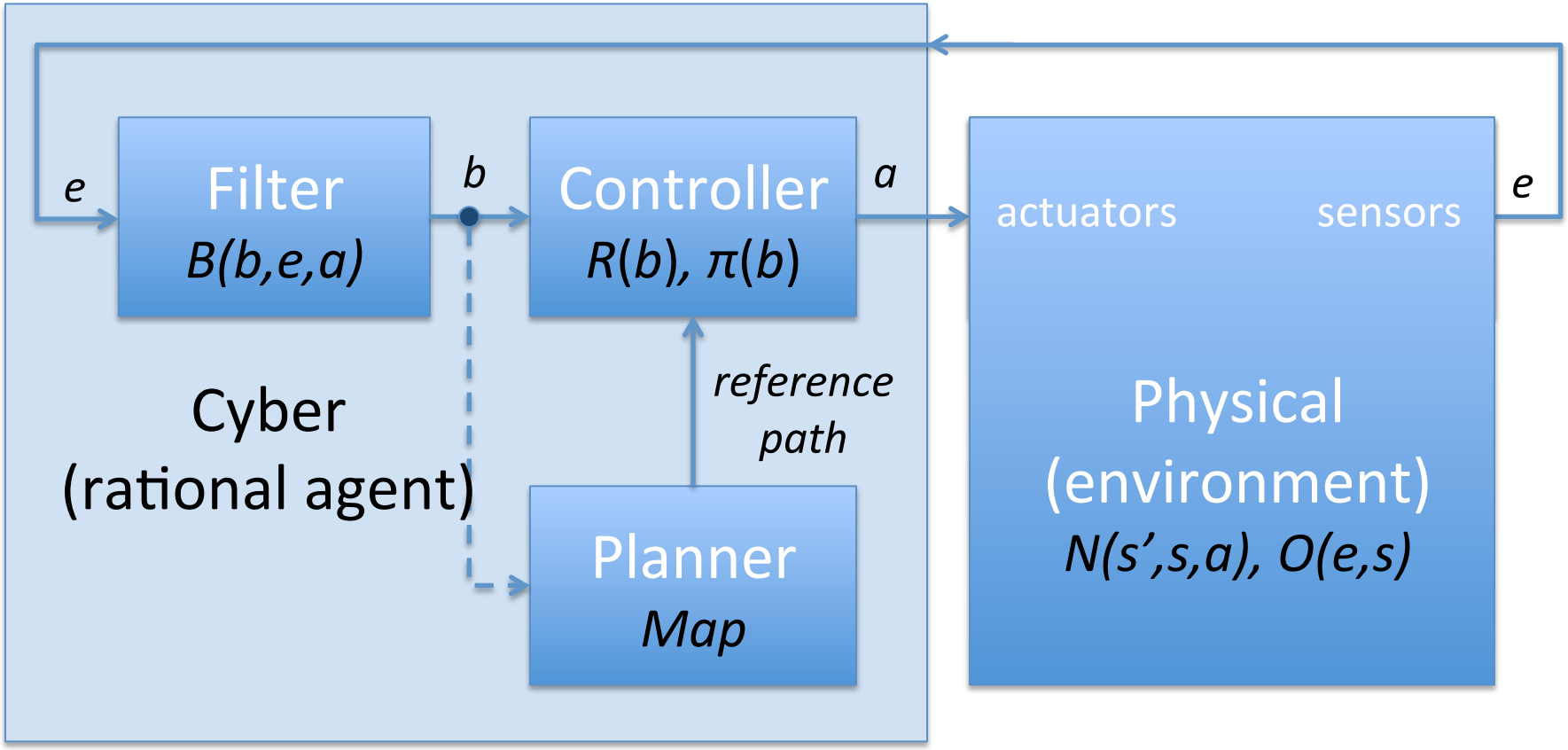
CPS as a Rational Agent: Courses



How do we deal with time?

- **Time triggered:** Real Time Systems, TT Ethernet
- **Event triggered:** Within the ESE courses

CPS as a Rational Agent: Courses

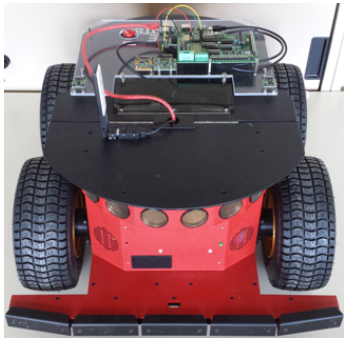


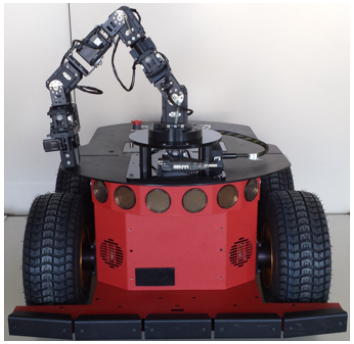
How do we implement all this on computers?

- **Hardware abstraction : Operating Systems, OS programming**

Try It Out In Our Lab: Rovers

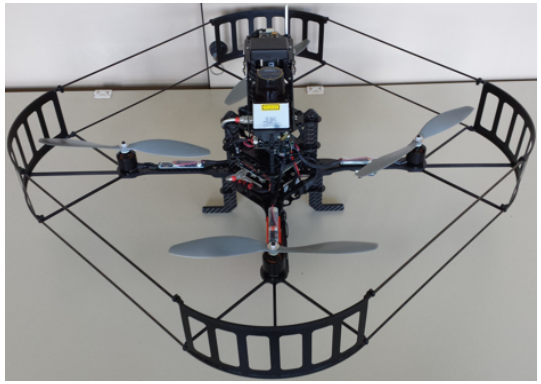
- **3 x Mobile Robots Pioneer 3-AT**
  - SICK LMS 100 Laser Scanner
    - 0.5 – 20 m operating range
    - 270° field of view
  - Cannon VC-C50i PTZ Analog Camera
  - UHF RFID-Reader
  - Cyton Gamma 300 Manipulator Arm
    - 300 g payload
    - 53.4 cm total reach
  - Sonar Distance Sensors
  - Bumper Switches





Try It Out In Our Lab: Quadcopters

- **2 x AscTec Pelican Drones**
  - Laser Scanner 0.06 – 4 m range
  - CMOS Camera
  - 1.6 GHz Intel Atom Processor Board
  - 2.1 GHz Intel Core i7 Quad-Core Board
  - Linux Operating System



- **3 x Parrot AR.Drone2.0**
  - Front (720p) and Floor (QVGA) Camera
  - Sonar Distance Sensors
  - Controllable via Smart Phone App

Projects and MS Thesis: Check them Out!

- https://ti.tuwien.ac.at/cps/research/projects
- https://ti.tuwien.ac.at/cps/teaching/practicals