

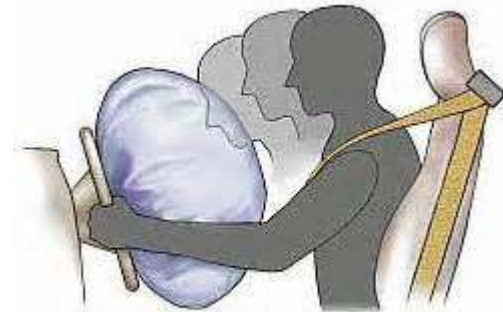
Cyber-Physical Systems Challenge of the 21st Century

Radu Grosu

**Cyber-Physical-Systems Group
Computer-Engineering Institute**

Quick History

Embedded Systems
1980: e.g. airbag

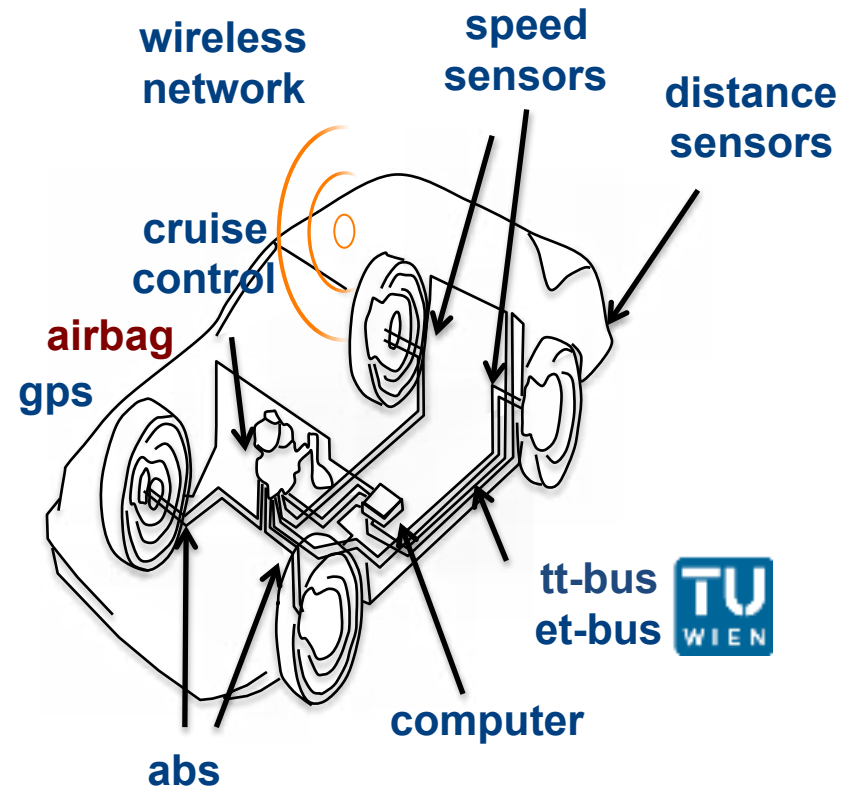


Quick History

- > 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

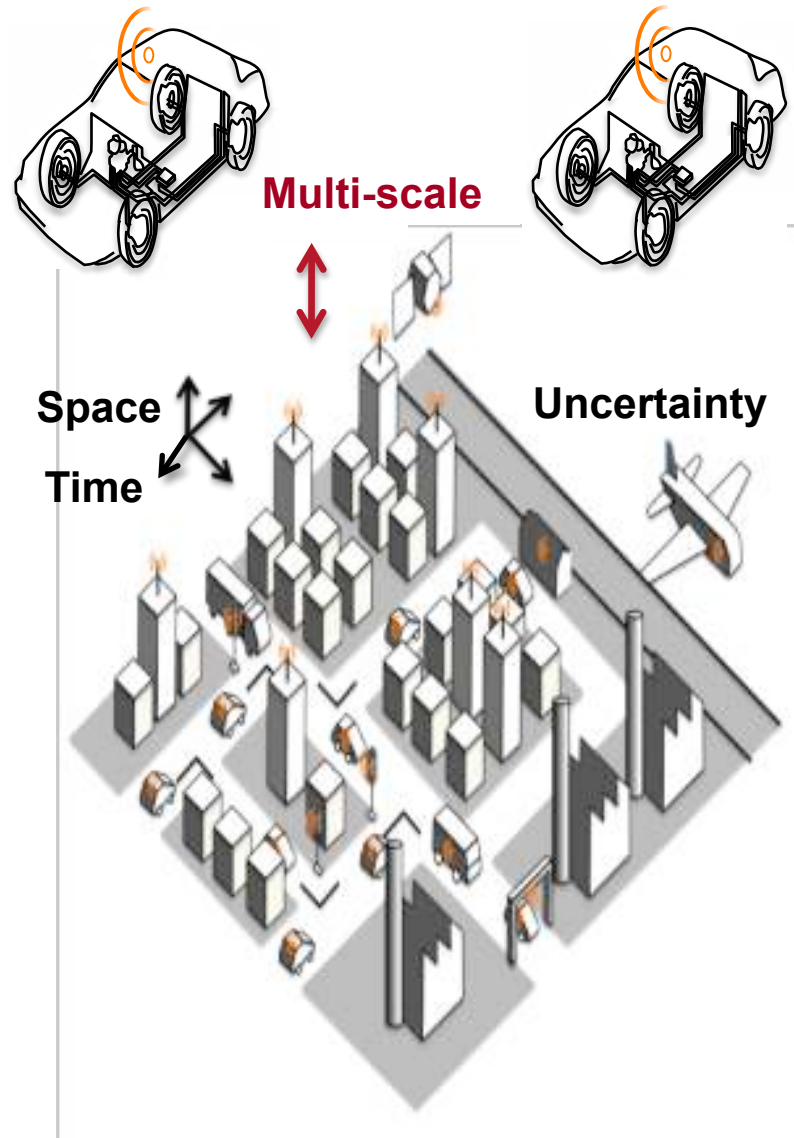


Quick History

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



Vienna, Austria

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?



Unmanned Trains



Unmanned Cars



Unmanned Aerial Vehicle



Unmanned Underwater Vehicle



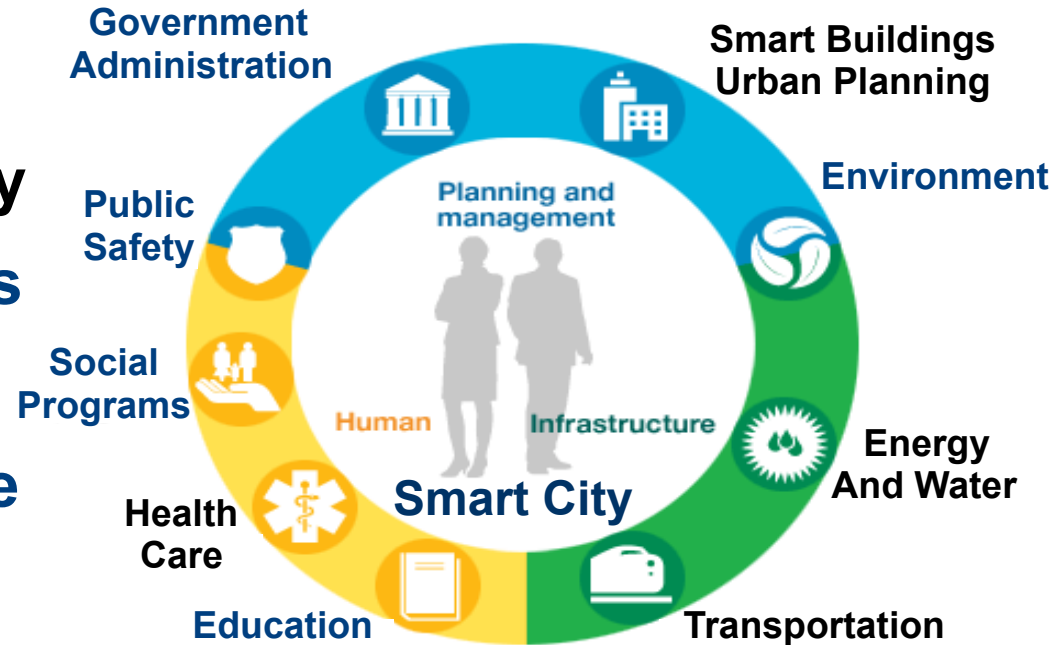
Unmanned Factory



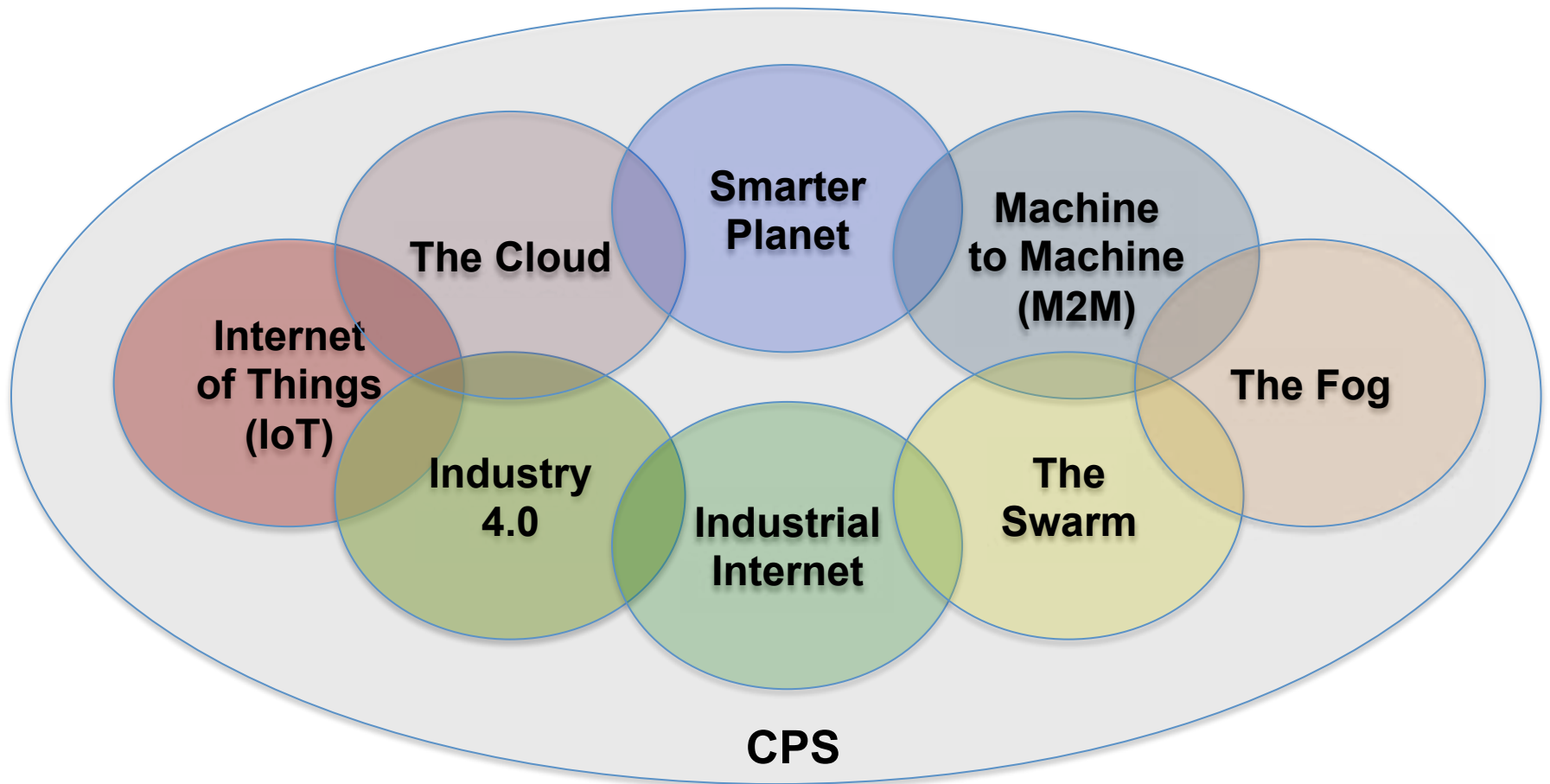
Cyber Biological

What are the Grand Challenges?

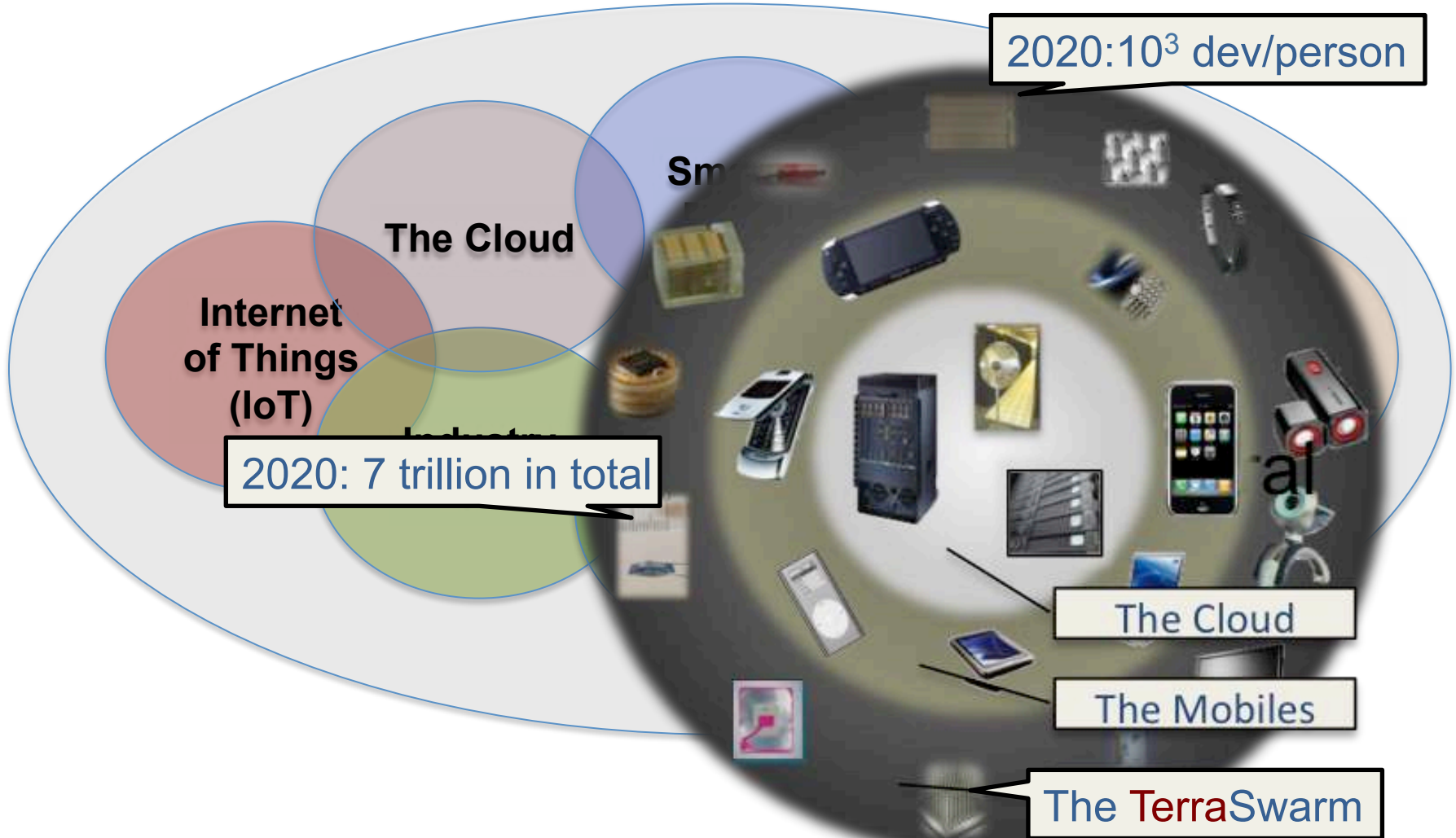
- Zero traffic-fatalities
- Blackout-free electricity
- Energy-aware buildings
- On-the-fly production
- Everywhere health-care
- Max-yield agriculture



The CPS Ecosystem



The CPS Ecosystem



What are the Technical Challenges?

Mathematics

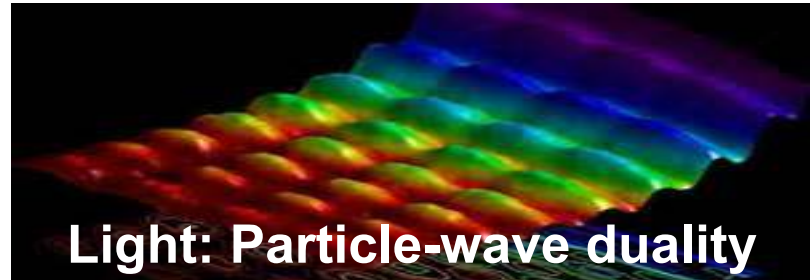
- Discrete-continuous
- Very different math

Architecture

- Huge complexity
- CPS-OS platform

Spacetime

- Various scales of ST
- ST-aware programs



What are the Technical Challenges?

Uncertainty

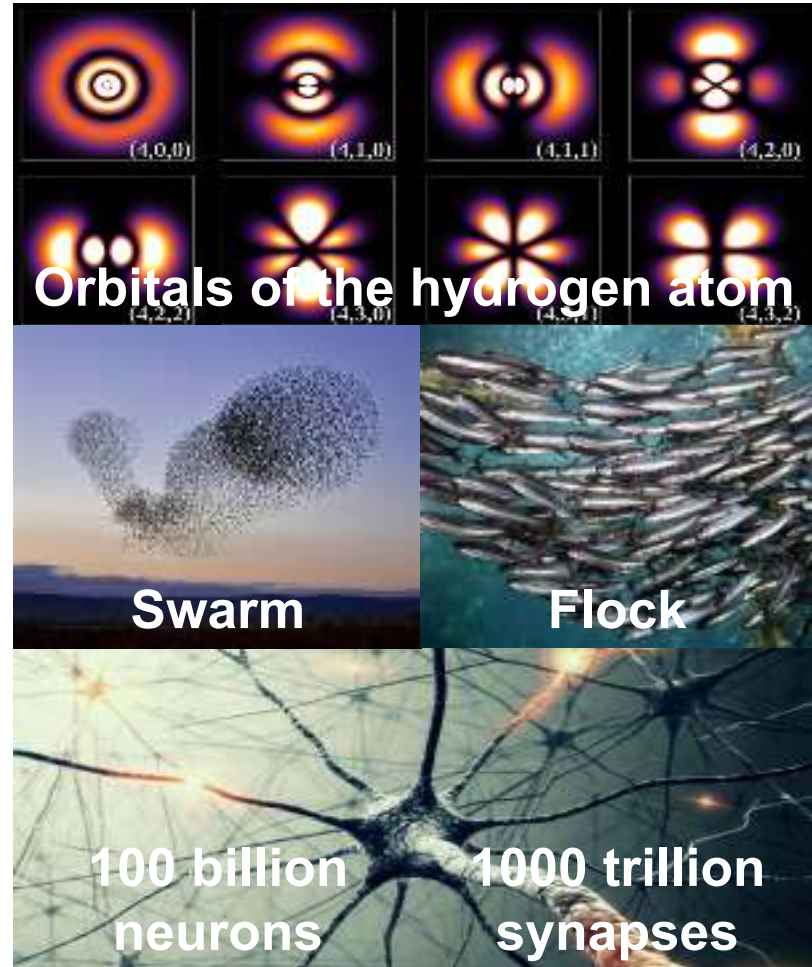
- Partial knowledge
- Limited resources

Safety

- Safety is in big no
- Emergent behavior

Smartness

- Adapting is in big no
- Neural circuits



What About Education?

Recent past (1980-2010s)

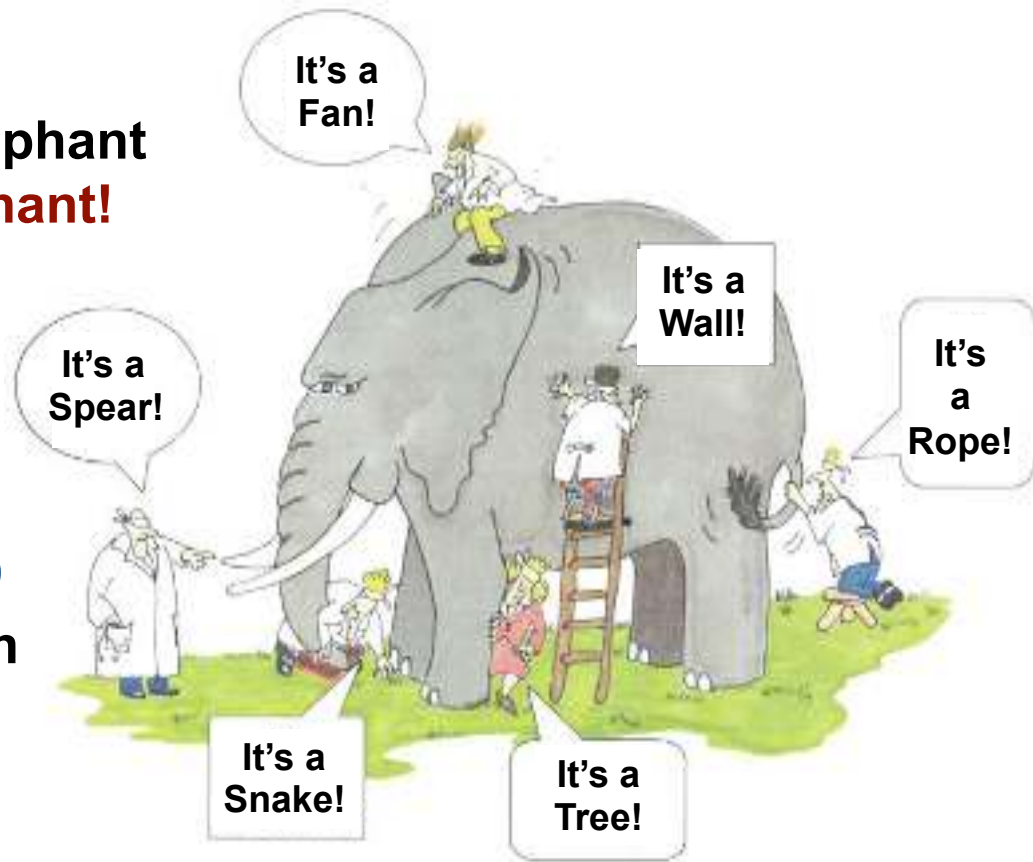
- Blind man assessing an elephant
- **Blind man building an elephant!**

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**

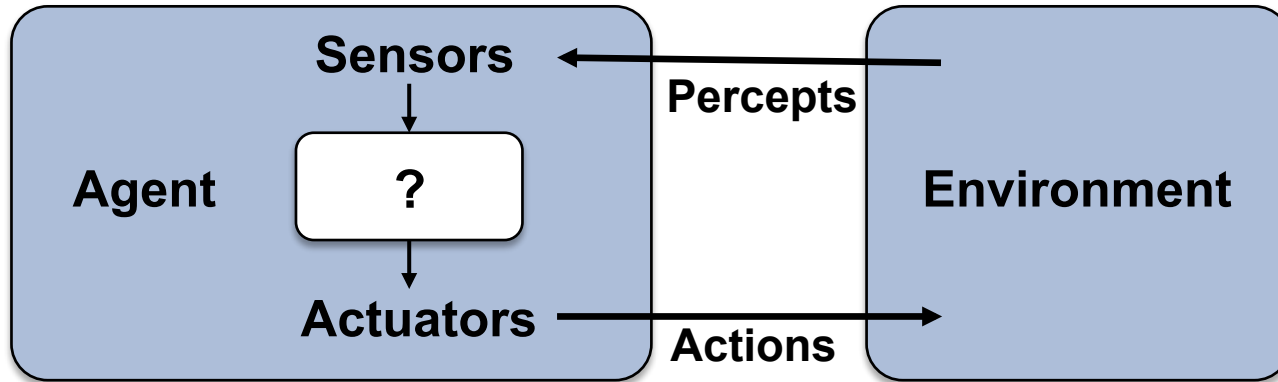


What is in Store for Us?





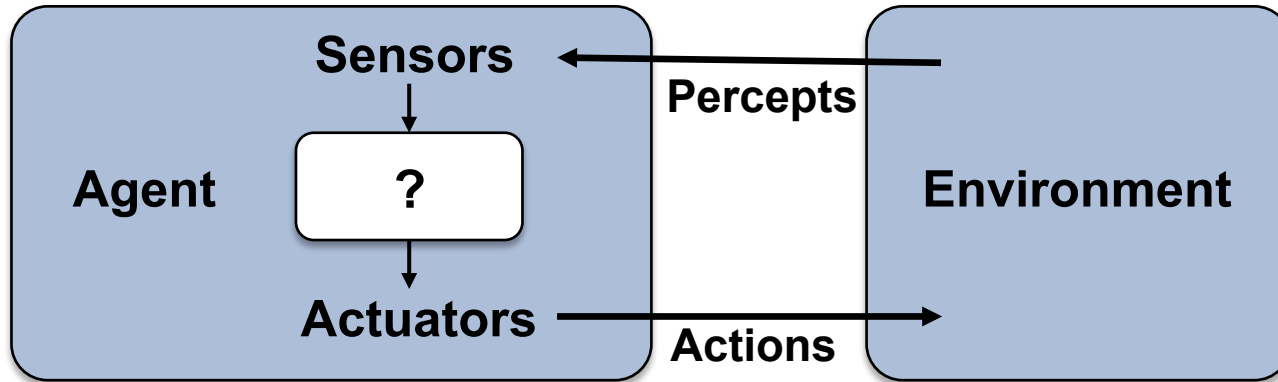
Acting Rationally



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

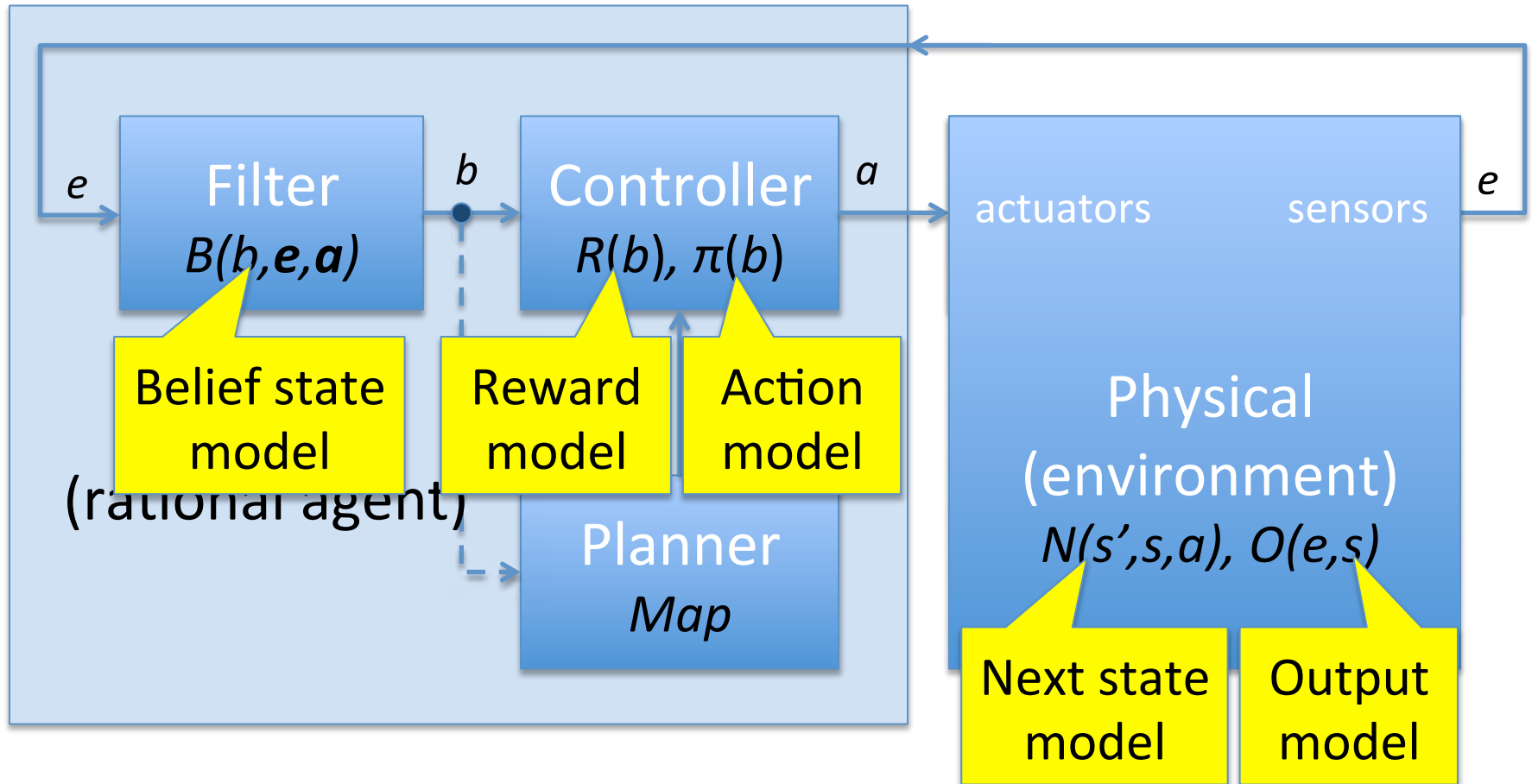


Rational Agent Extension of Computer Agent

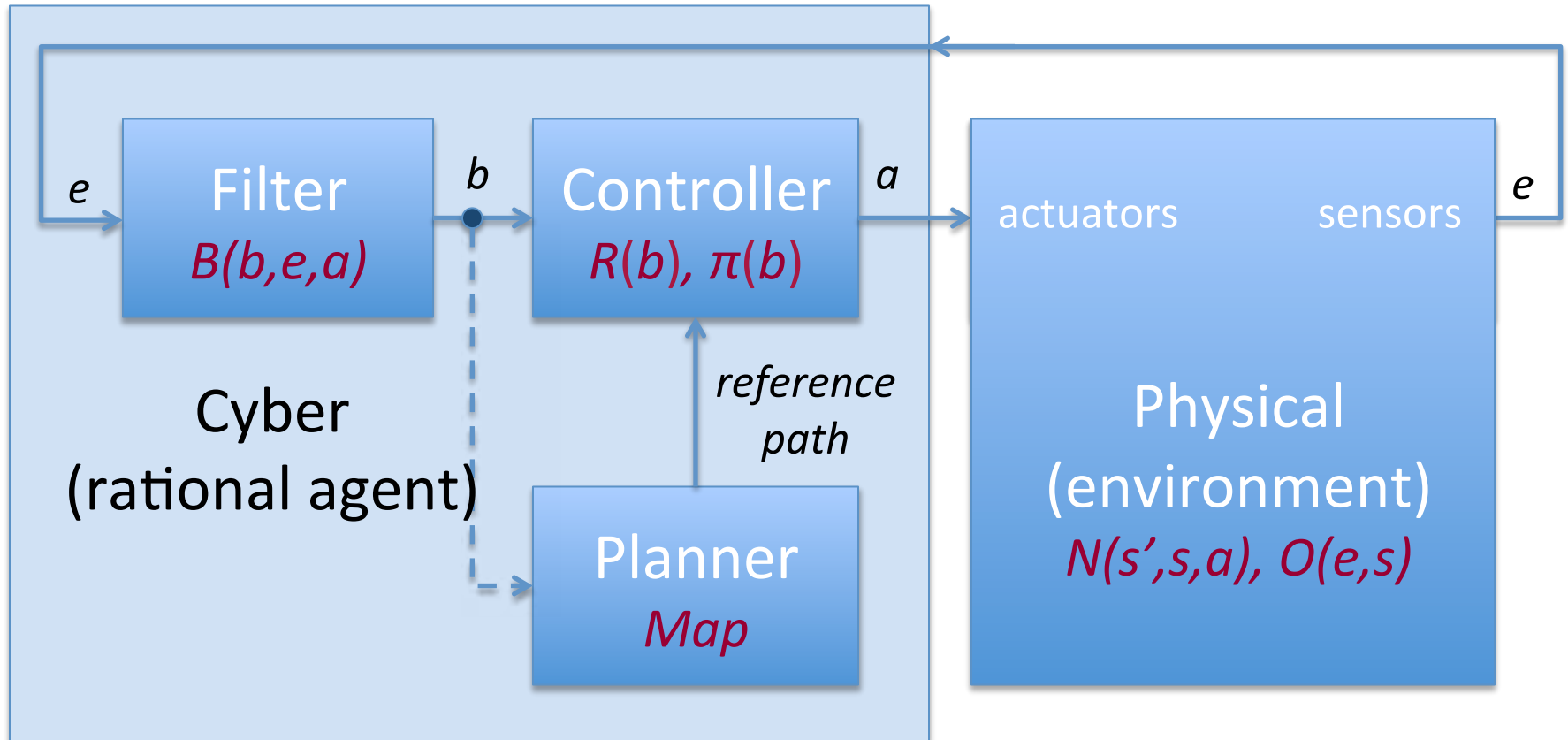
- Acts so as to **achieve the best outcome**, and when
- There is **uncertainty**, the **best expected outcome**

In our classes: Smart = Rational !

CPS as a Rational Agent

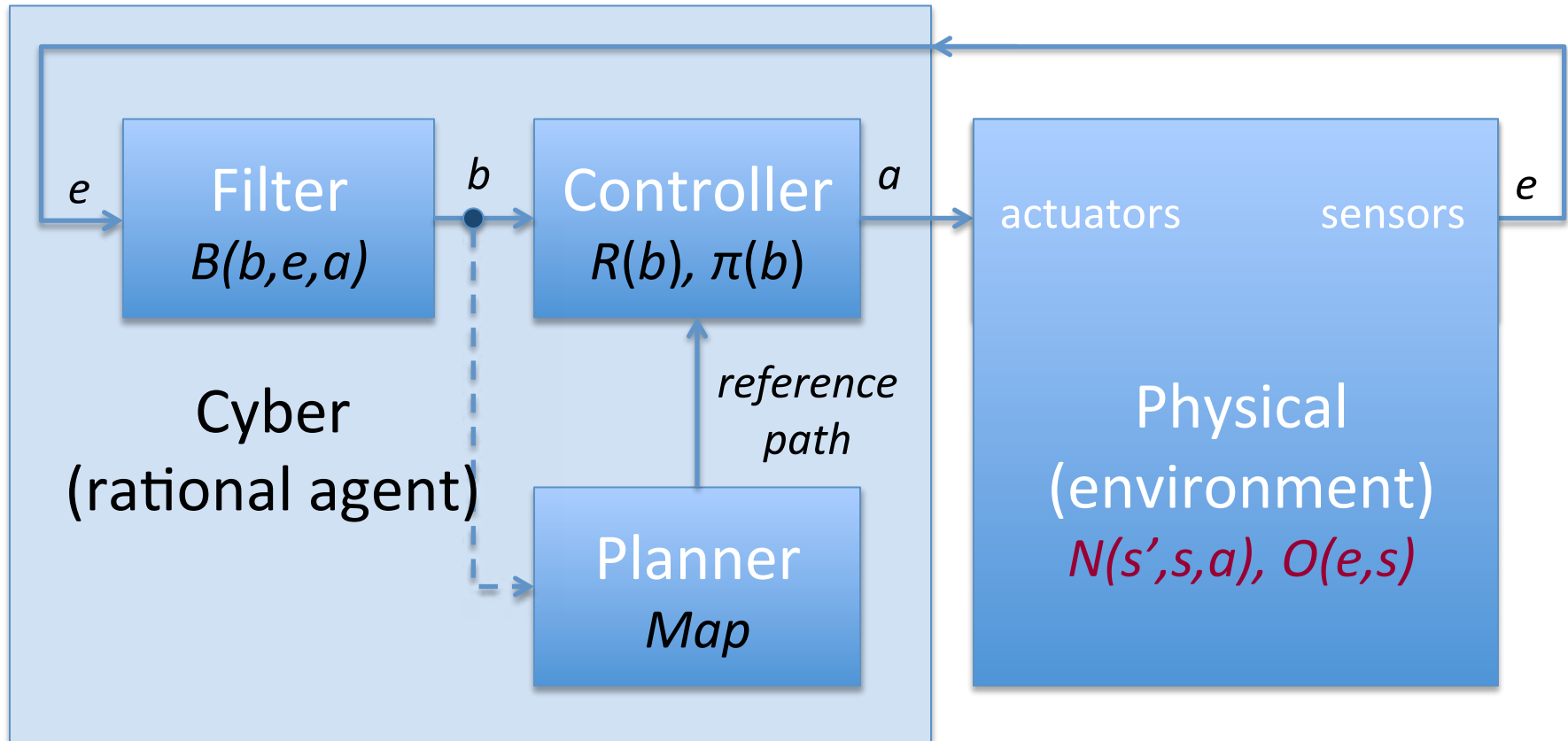


CPS as a Rational Agent: Modeling



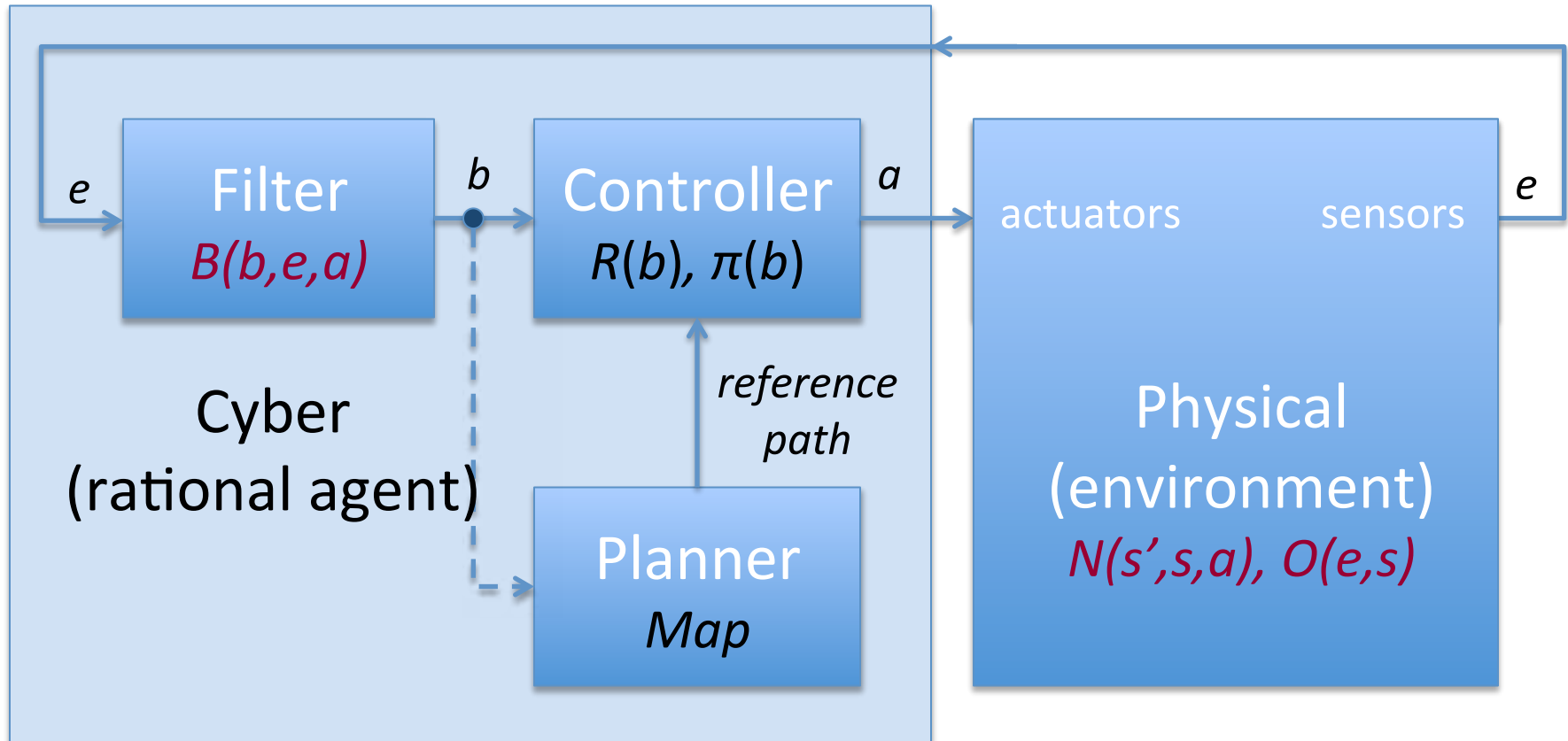
What mathematical form have **all the models above?**

CPS as a Rational Agent: Learning



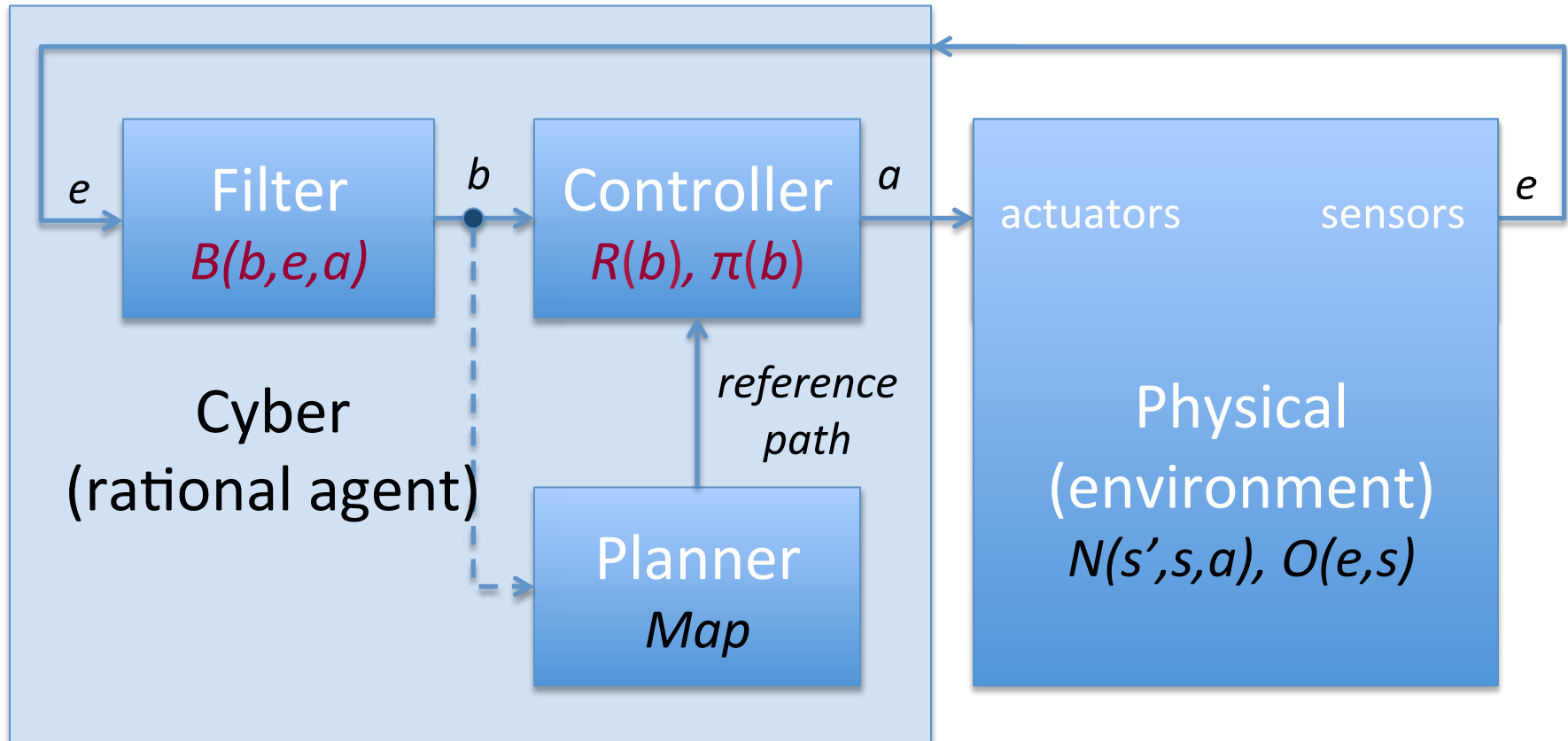
Learn **next-state/output models** from **input/output traces**.

CPS as a Rational Agent: State Estimation



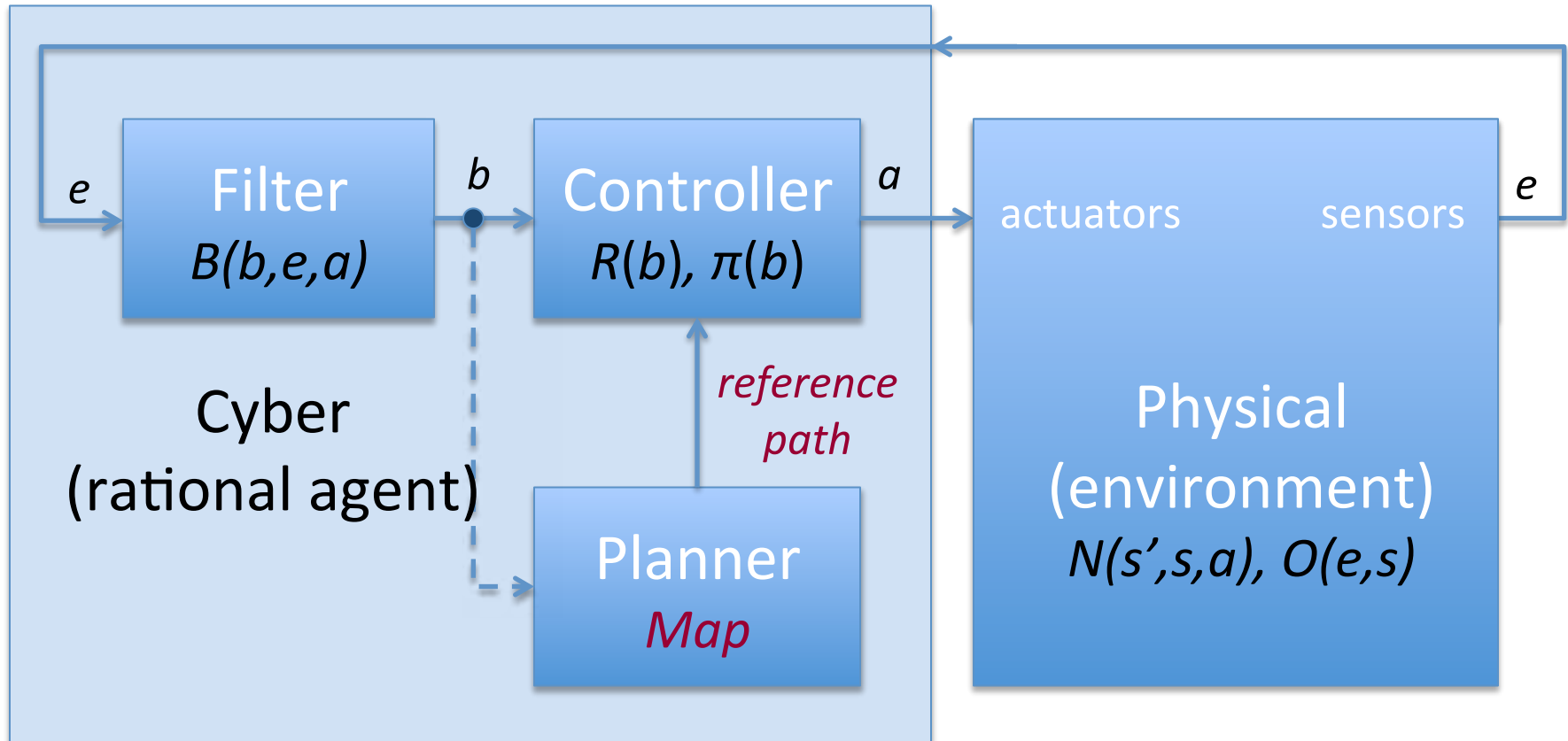
Synthesize **belief state** from **next-state/output models**.

CPS as a Rational Agent: Optimal Control



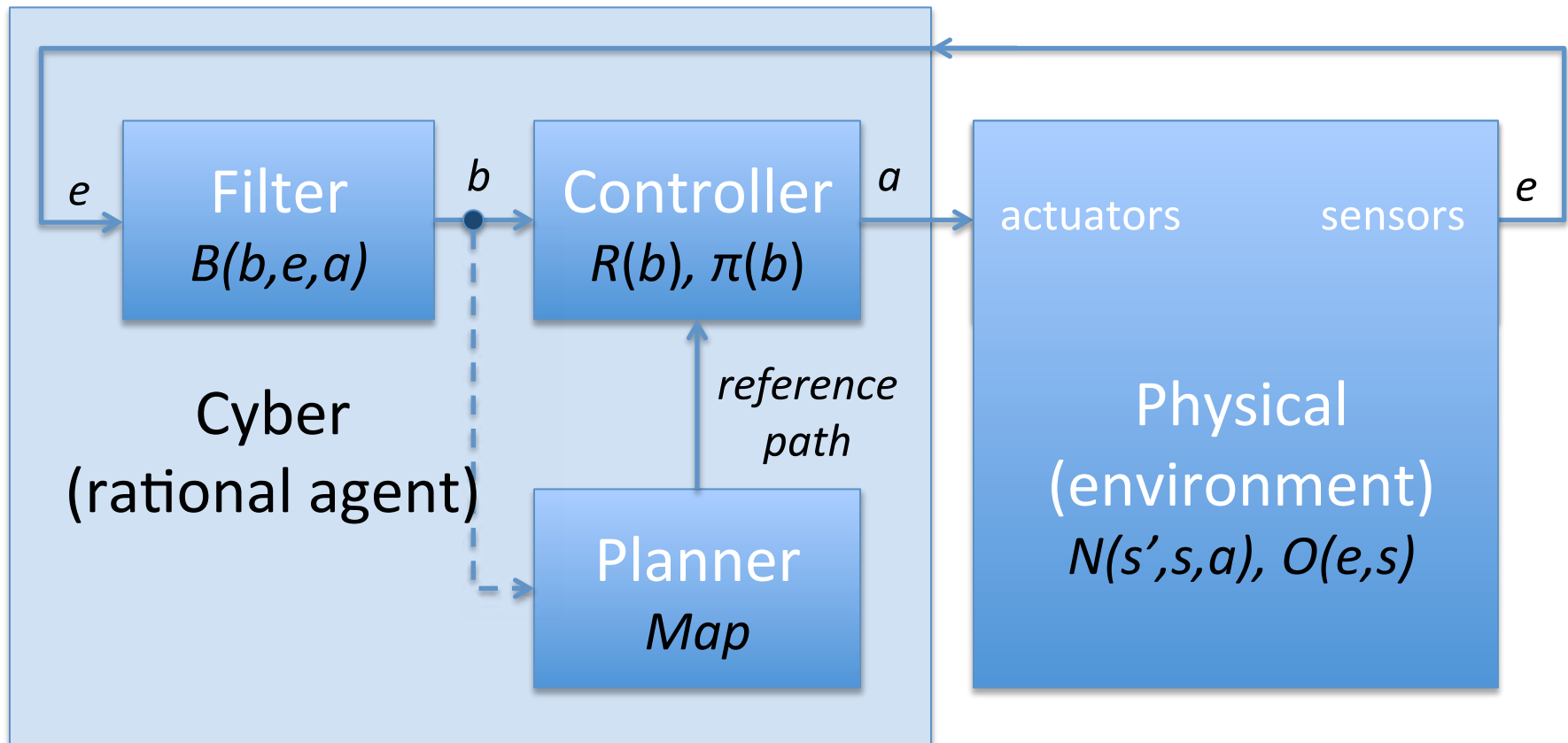
Synthesize **controller** from **belief-state** and **reward models**.

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

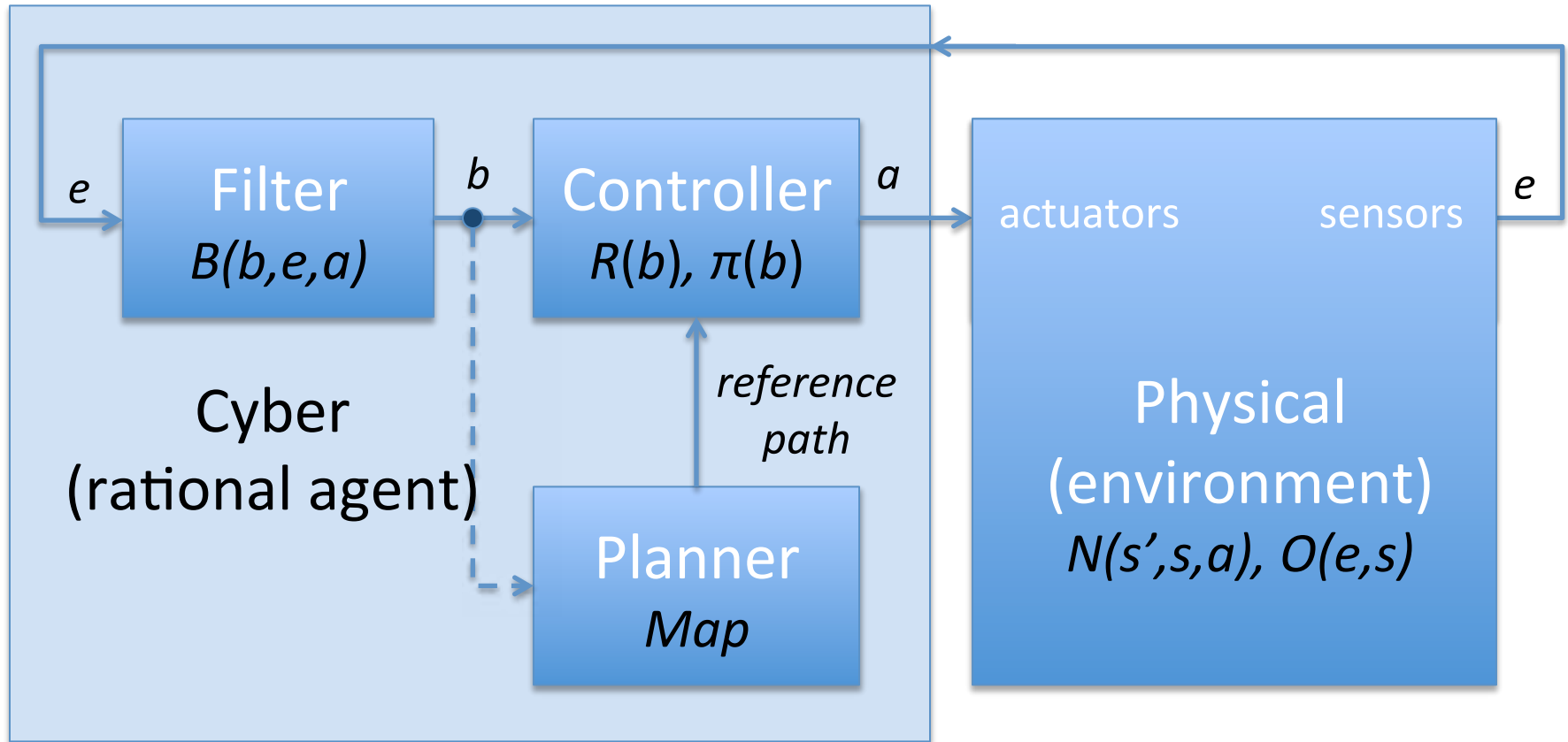
The syllogism of Greek philosopher Aristotle (nondet.)

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

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

- **Main pattern:** $P(A) P(B | A) \blacksquare P(A \blacktriangle B) \blacksquare P(B) P(A | B)$
- **Advantage:** Shades of gray (quantitative)

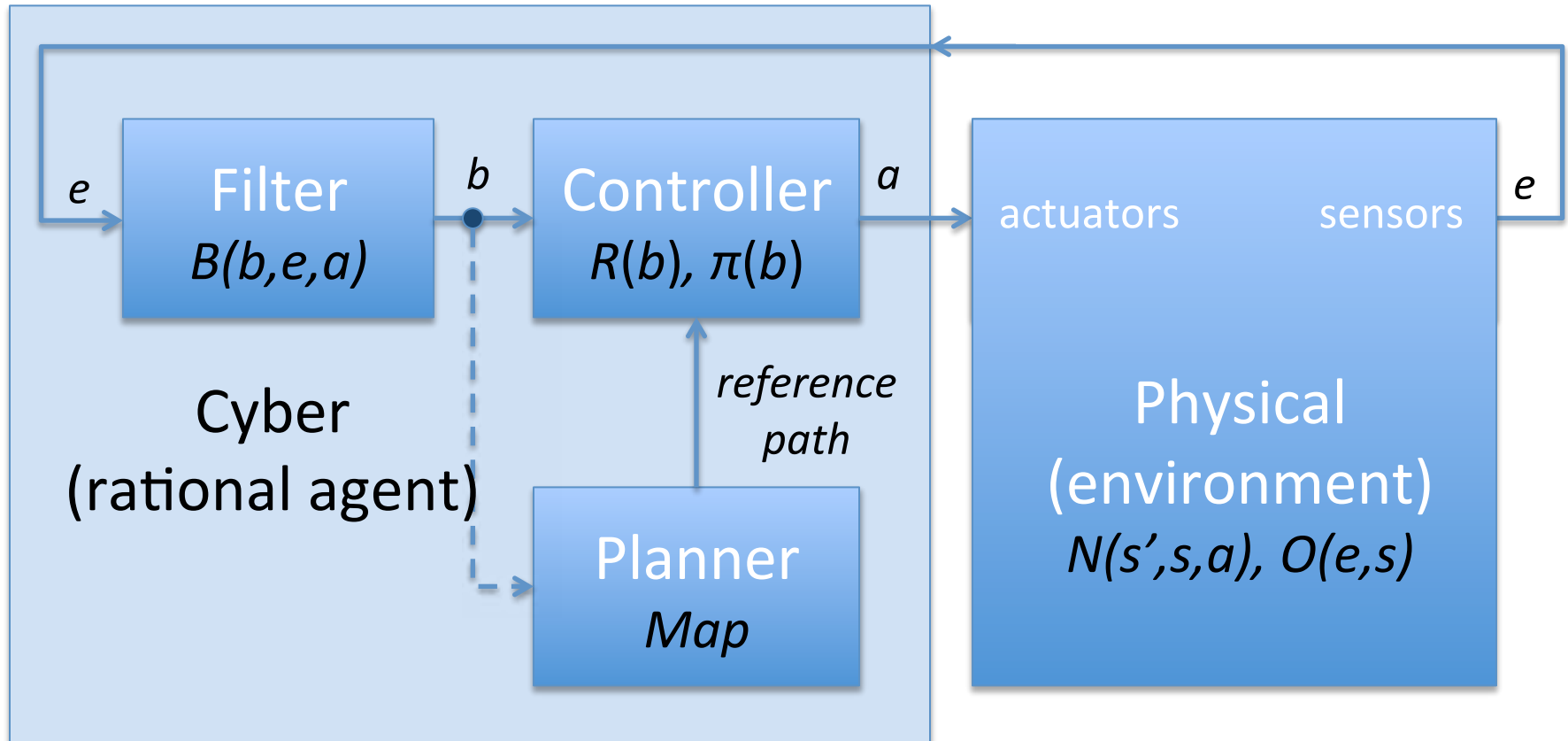
CPS as a Rational Agent: Courses



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>

