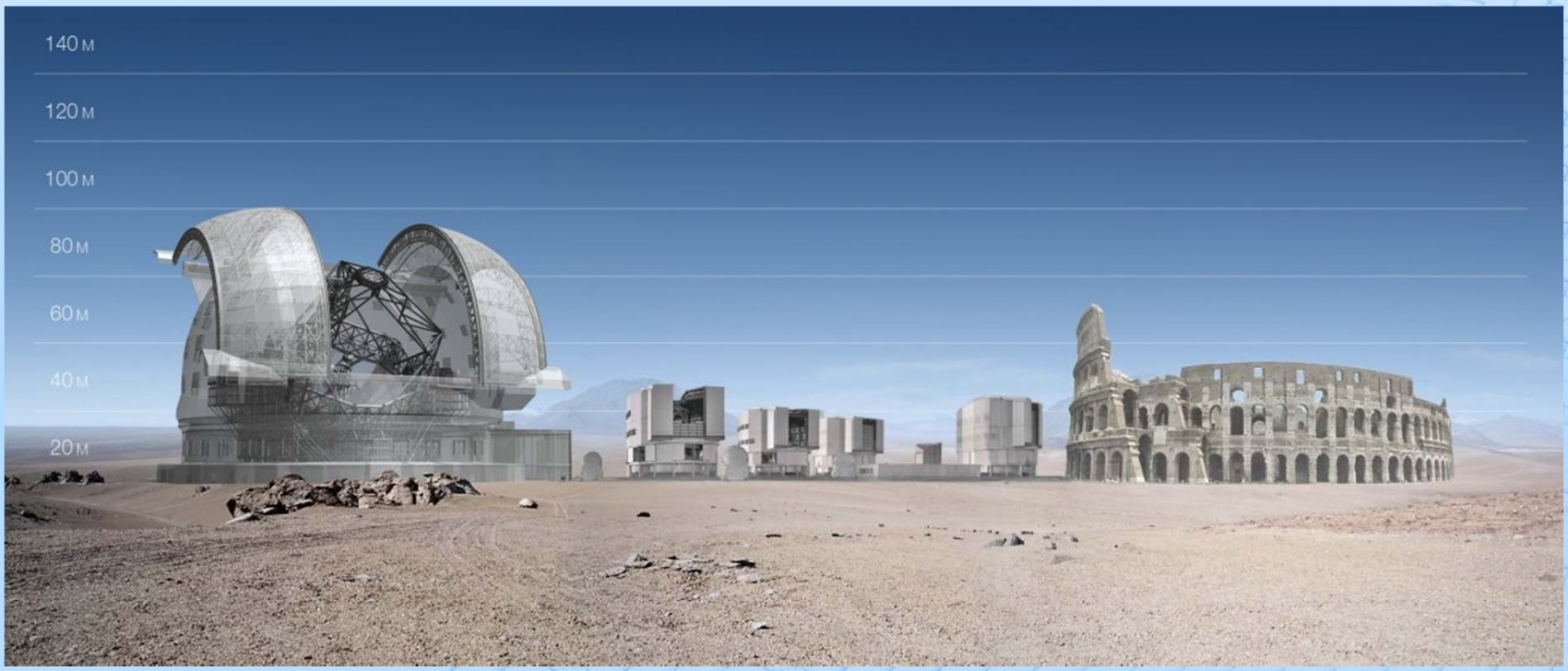
ESO
European Organisation for Astronomical Research in the Southern Hemisphere

Towards a State Based Control Architecture for Large Telescopes: Laying a Foundation at the VLT

Robert Karban, Nicholas Kornweibel (ESO, Garching, Germany)

Daniel Dvorak, Michel Ingham, David Wagner (Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA)



About Robert Karban

ESO
European Organisation for Astronomical Research in the Southern Hemisphere

Outline

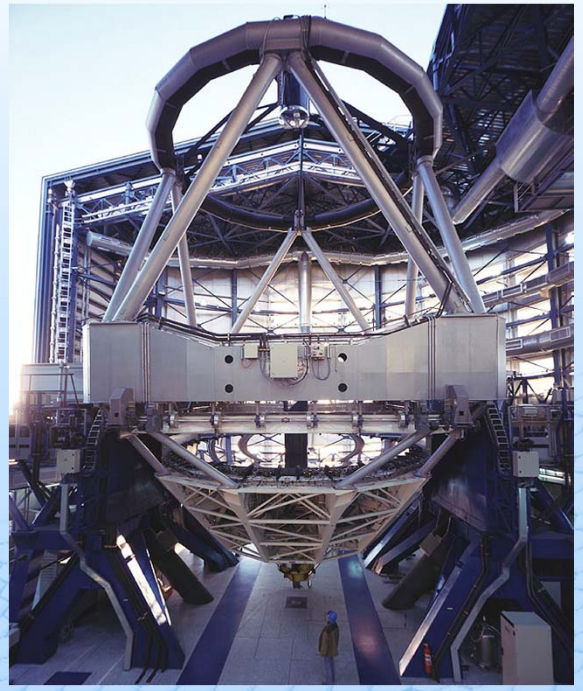
ESO
European Organisation for Astronomical Research in the Southern Hemisphere

- Context
- Architecture
- State Analysis
- VLT Field Testing
- Summary and Future Work

Context - ESO major projects

ESO
European Organisation for Astronomical Research in the Southern Hemisphere

Very Large Telescope (VLT)
Started 1988, in operation since 1999

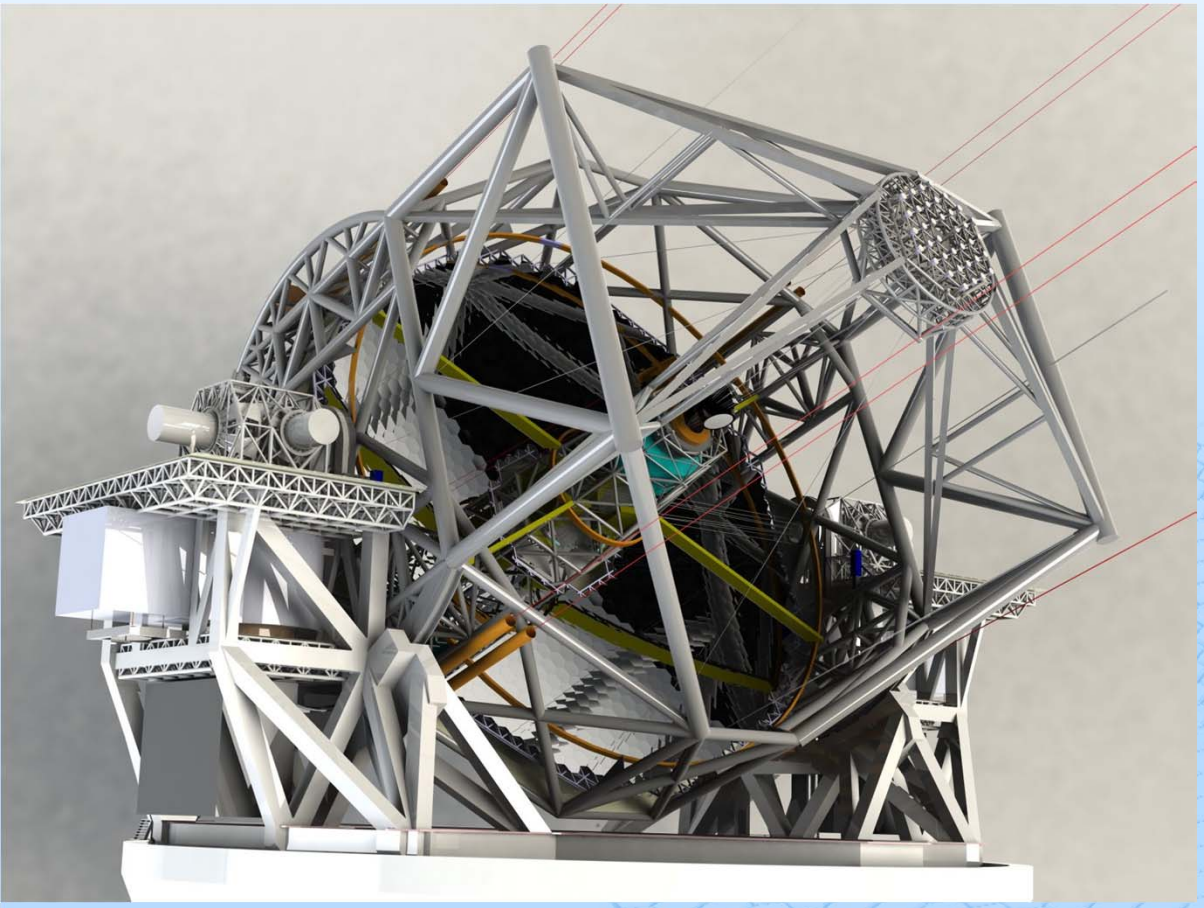


Atacama Large Millimeter Array (ALMA)
Europe-US-Japan
Started 1998, Early Science
Operations started in October 2011.
Completion expected in 2012

Images on this slide were produced by ESO

Context - The E-ELT

ESO
European Organisation for Astronomical Research in the Southern Hemisphere



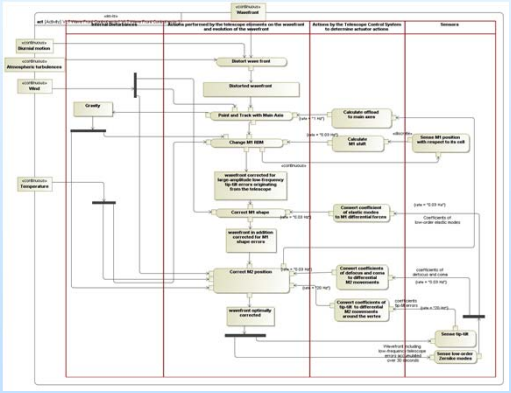
- 40 m class mirror
- Will be the largest optical/near-infrared telescope in the world
- Gather 15 times more light than any other telescope today.
- Exciting science: extra solar planets and discs, galaxy formation, dark energy/dark matter, and frontiers of physics.
- If approved construction could start in 2012 with beginning of operations 2020-2022

Images on this slide were produced by ESO

Context - Challenges for the Control System

ESO
European Organisation for Astronomical Research in the Southern Hemisphere

VLT Wavefront control



- 600 tons of steel and glass
- 200 actuators, 3 mirrors
- 2000 I/O points
- Small data volume
- Some interacting, distributed control loops (0.01Hz->50Hz)
- Overall function and performance of the telescope is allocated to the control system

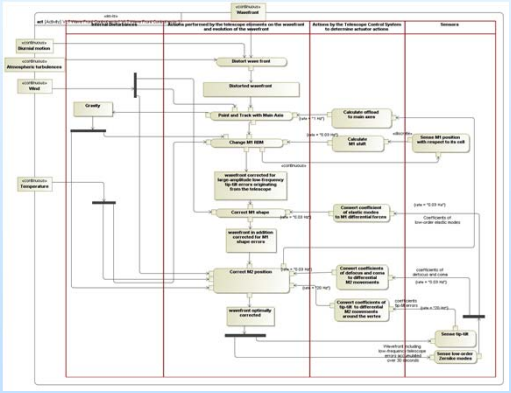
E-ELT Wavefront control

- 10000 tons of steel and glass
- 20000 actuators, 1000 mirrors
- 50000 I/O points, (M1 has 15000 alone)
- Large data volume (700Gflops/s, 17Gbyte/s), only engineering data
- Multitude of interacting, distributed control loops (0.01Hz->kHz rates)
- Overall function and performance of the telescope is allocated to the control system

Context - Challenges for the Control System

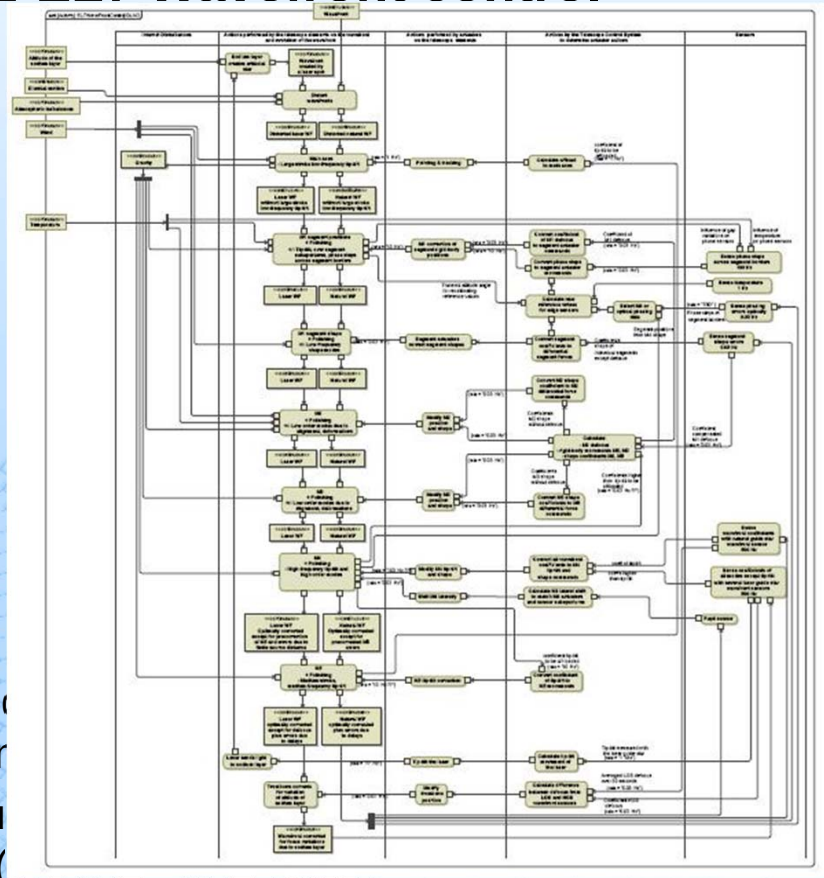
ESO
European Organisation for Astronomical Research in the Southern Hemisphere

VLT Wavefront control



- 600 tons of steel and glass
- 200 actuators, 3 mirrors
- 2000 I/O points
- Small data volume
- Some interacting, distributed control loops (0.01Hz->50Hz)
- Overall function and performance of the telescope is allocated to the control system

E-ELT Wavefront control

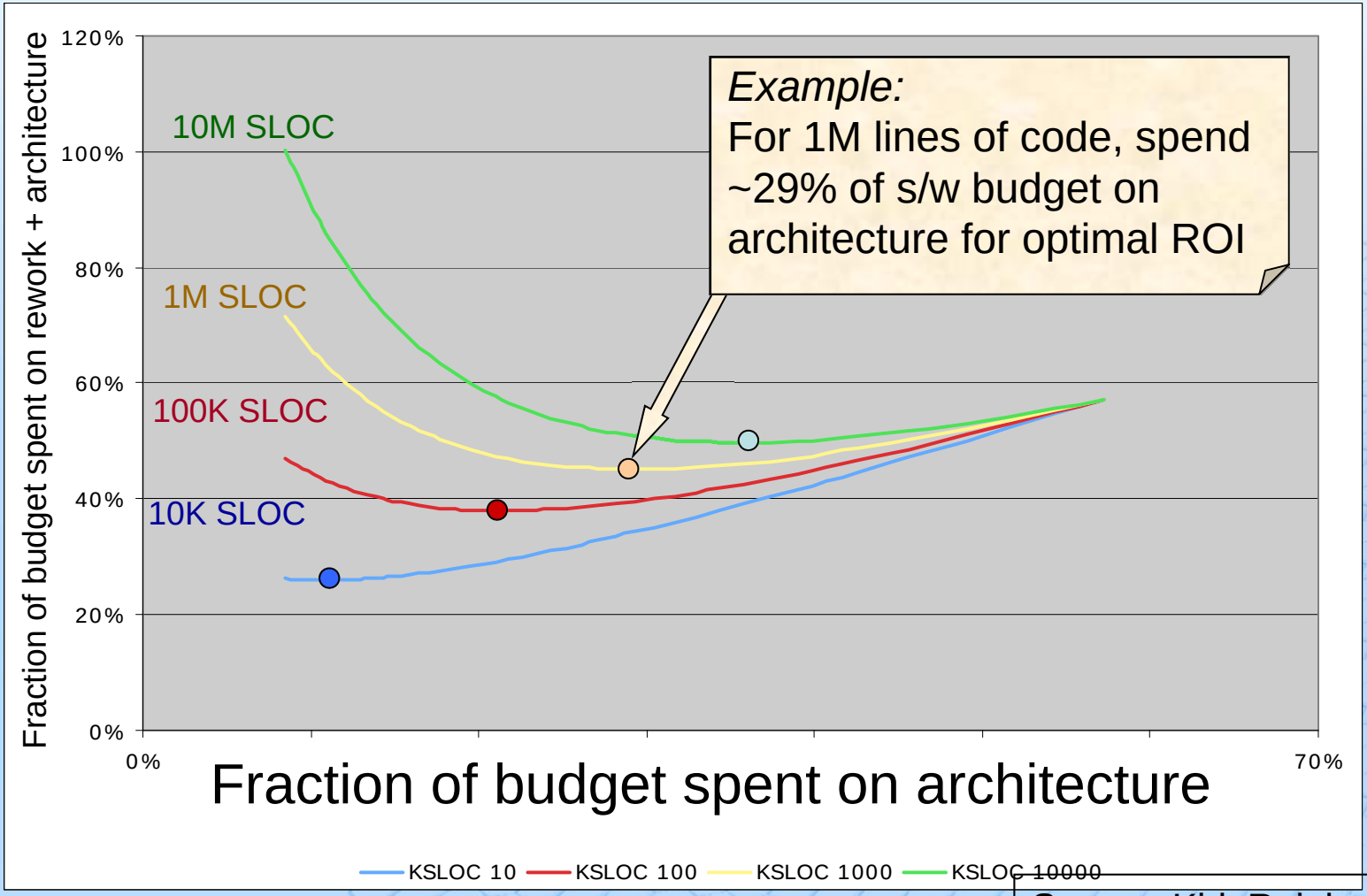


- 10000
- 20000
- 50000
- Large
  only er
- Multitu
  loops (
- Overall function and performance of the telescope is allocated to the control system

Architecture Investment "Sweet Spot"

ESO
European Organisation for Astronomical Research in the Southern Hemisphere

Predictions from COCOMO II model for software cost estimation

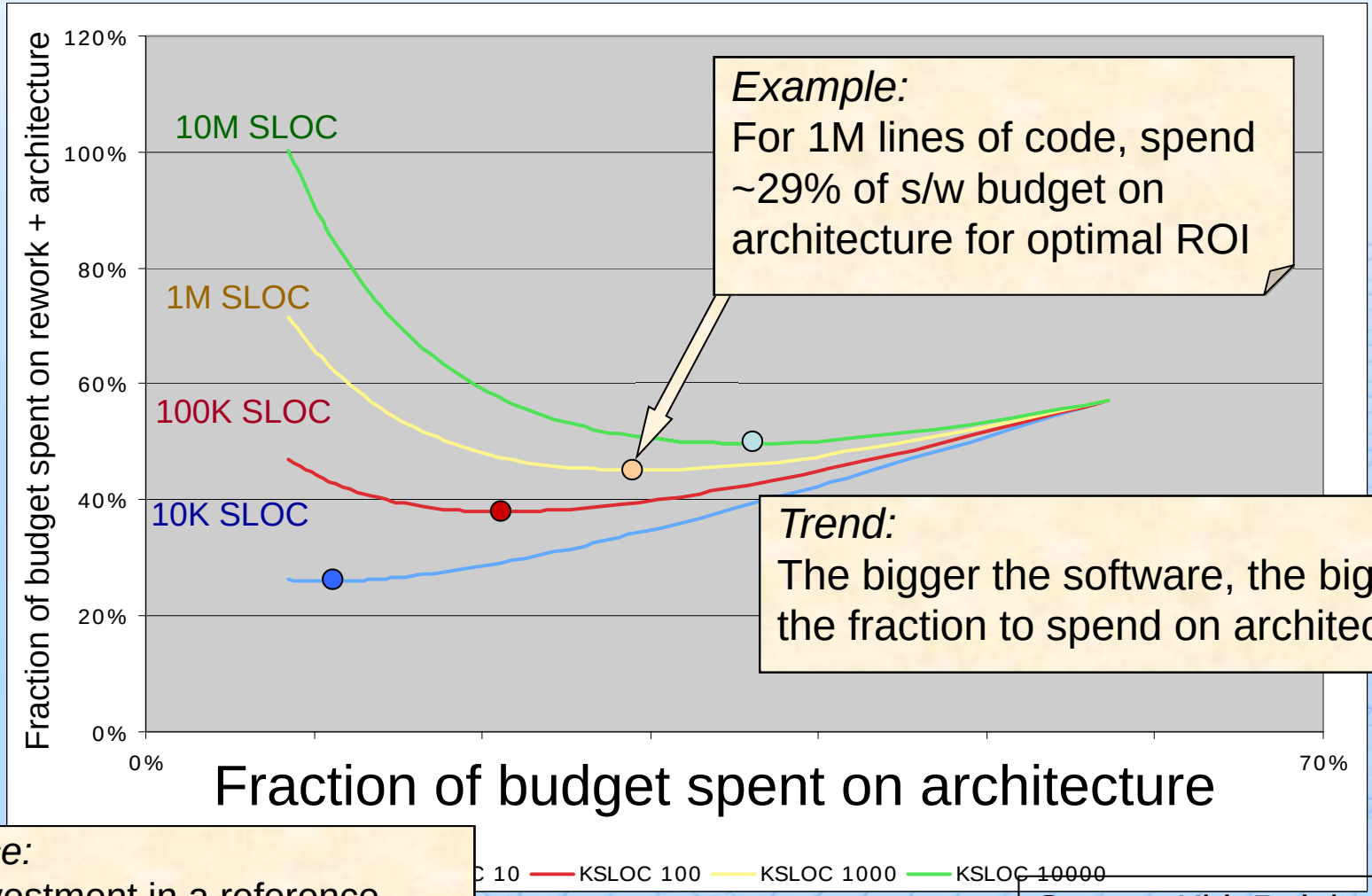


Source: Kirk Reinholtz, JPL

Architecture Investment "Sweet Spot"

ESO
European Organisation for Astronomical Research in the Southern Hemisphere

Predictions from COCOMO II model for software cost estimation



Example:
For 1M lines of code, spend ~29% of s/w budget on architecture for optimal ROI

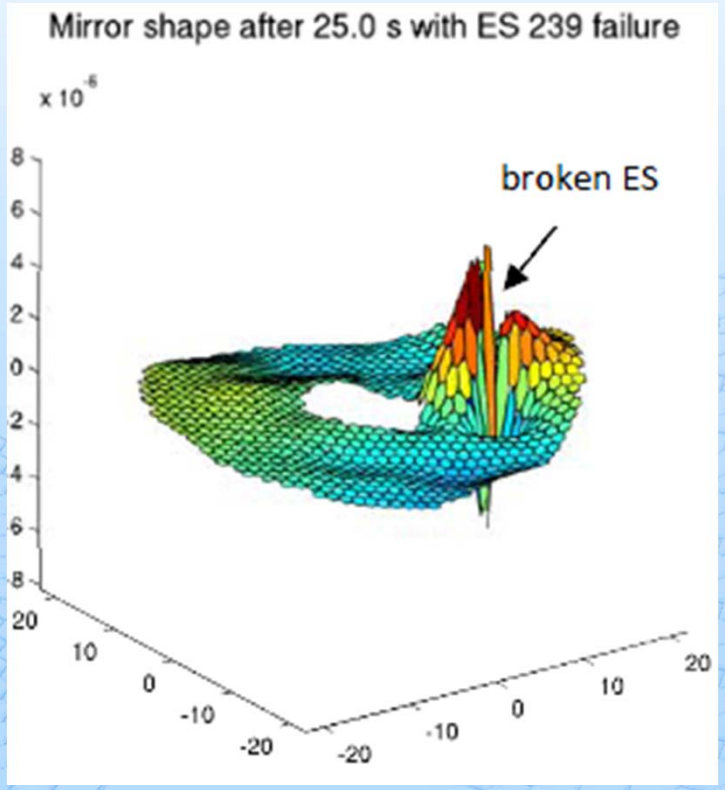
Trend:
The bigger the software, the bigger the fraction to spend on architecture

Inference:
Prior investment in a reference architecture pays dividends

Source: Kirk Reinholtz, JPL

Architecture - Goals

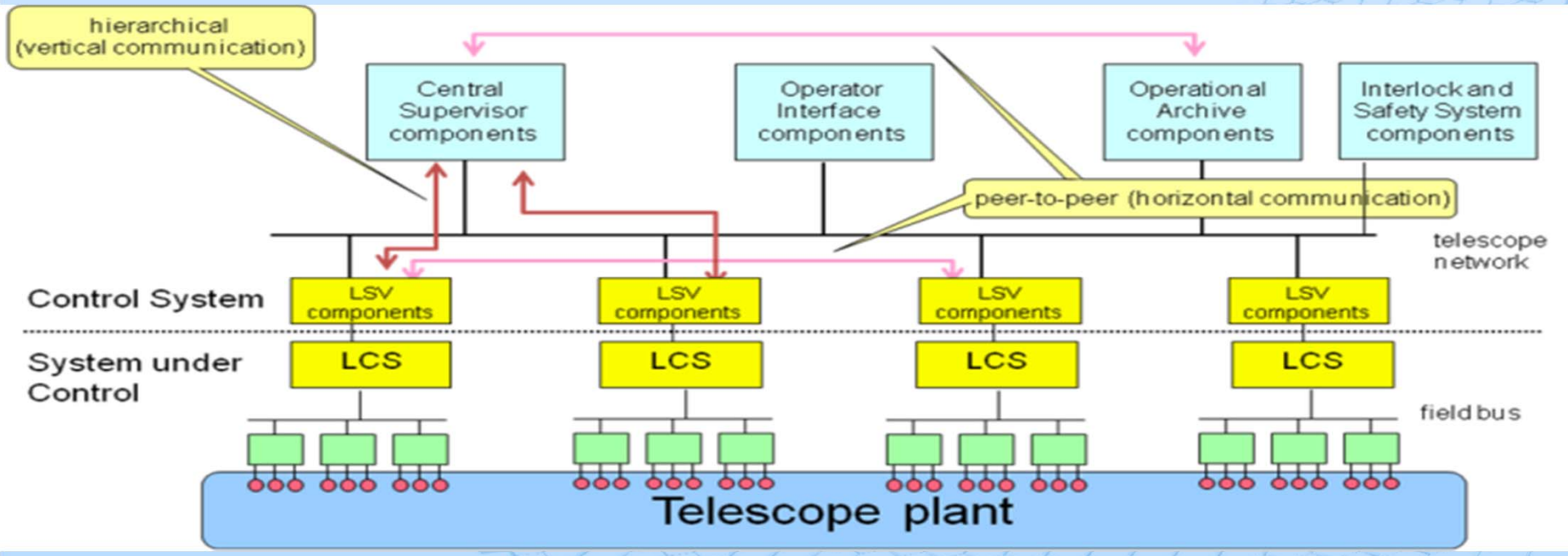
- Address the functional need derived from the wave front control strategy
- Contain system complexity
- Promote modifiability and scalability (and long-term maintainability)
- Enable high availability and fault tolerance
- Conceptual Integrity



Conceptual Architecture

- Data driven
- Decentralized
- Separate Domain Knowledge

- Integrate heterogeneous Control Systems
- Define a framework and design rules



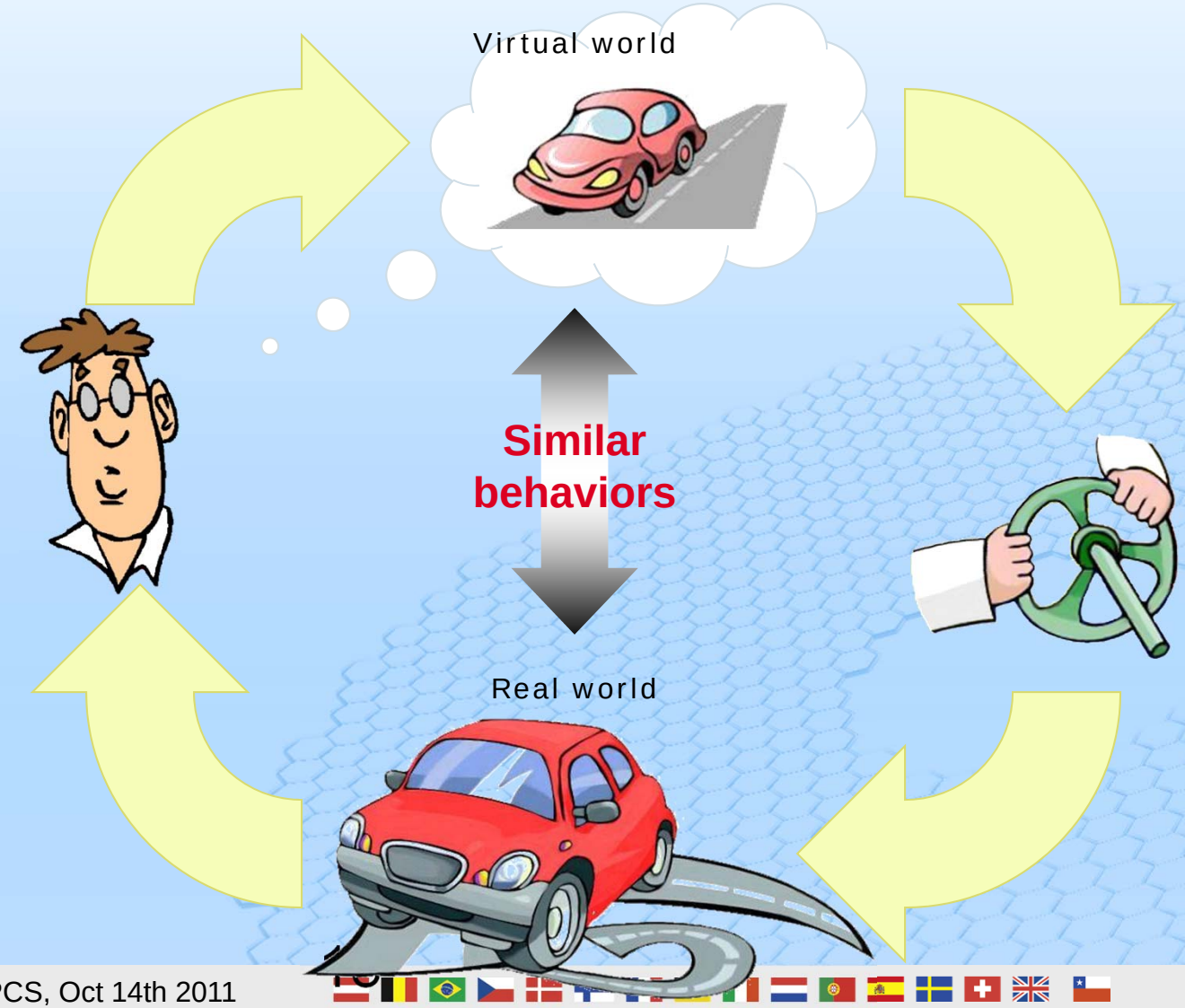
State Analysis – What does it mean?

ESO
European Organisation for Astronomical Research in the Southern Hemisphere

- Imagine driving a car.
  As a driver you:
  - Have destinations and deadlines
  - Plan a route
  - Rely on gauges and your own senses
- In other words, you:
  - Set objectives regarding the **state** of the world
  - Monitor the **state** of the world
  - Form a coherent notion of the **state** of the world
    and you anticipate its changes
- State is central

State Analysis - The “Control Diamond”

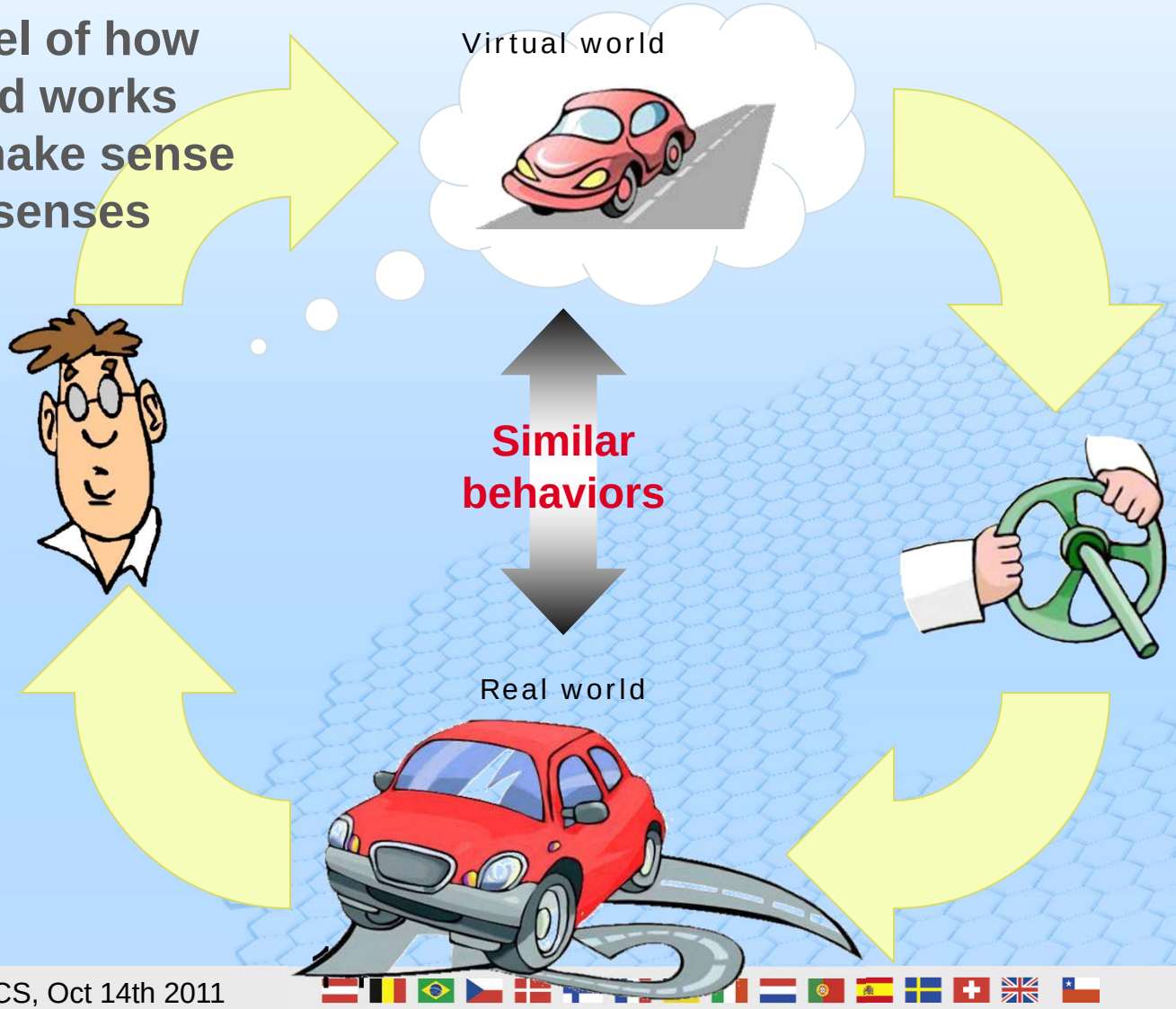
ESO
European Organisation for Astronomical Research in the Southern Hemisphere



State Analysis - The “Control Diamond”

ESO
European Organisation for Astronomical Research in the Southern Hemisphere

Our model of how the world works helps us make sense of our senses



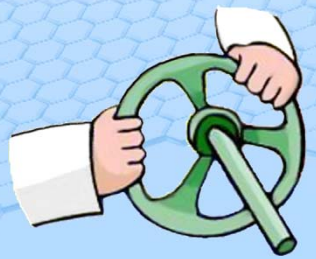
State Analysis - The “Control Diamond”

ESO
European Organisation for Astronomical Research in the Southern Hemisphere

Our model of how the world works helps us make sense of our senses

Virtual world

Similar behaviors



Real world

We see, not what is, but what we perceive — with a little help from our senses

State Analysis - The “Control Diamond”

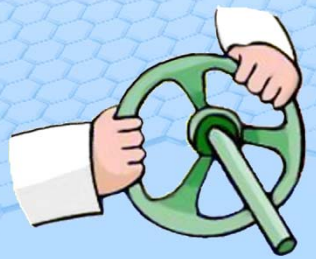
ESO
European Organisation for Astronomical Research in the Southern Hemisphere

Our model of how the world works helps us make sense of our senses

Virtual world

We react, not to things as they are, but rather to things as we perceive them

Similar behaviors



We see, not what is, but what we perceive — with a little help from our senses

Real world

State Analysis - The “Control Diamond”

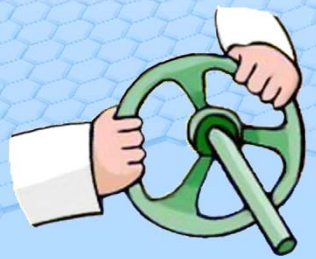
ESO
European Organisation for Astronomical Research in the Southern Hemisphere

Our model of how the world works helps us make sense of our senses

Virtual world

We react, not to things as they are, but rather to things as we perceive them

Similar behaviors



We see, not what is, but what we perceive — with a little help from our senses

Real world

Our actions are guided by what we expect them to do, given what we know

State Analysis - The “Control Diamond”

ESO
European Organisation for Astronomical Research in the Southern Hemisphere

Our model of how the world works helps us make sense of our senses

Virtual world

We react, not to things as they are, but rather to things as we perceive them

Similar behaviors

We see, not what is, but what we perceive — with a little help from our senses

Real world

Our actions are guided by what we expect them to do, given what we know

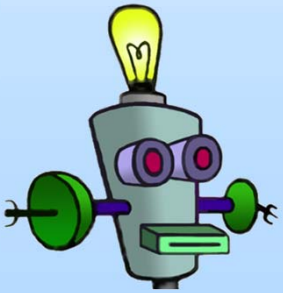
State Analysis - The “Control Diamond”

ESO
European Organisation for Astronomical Research in the Southern Hemisphere

Our model of how the world works helps us make sense of our senses

Virtual world

We react, not to things as they are, but rather to things as we perceive them



Similar behaviors

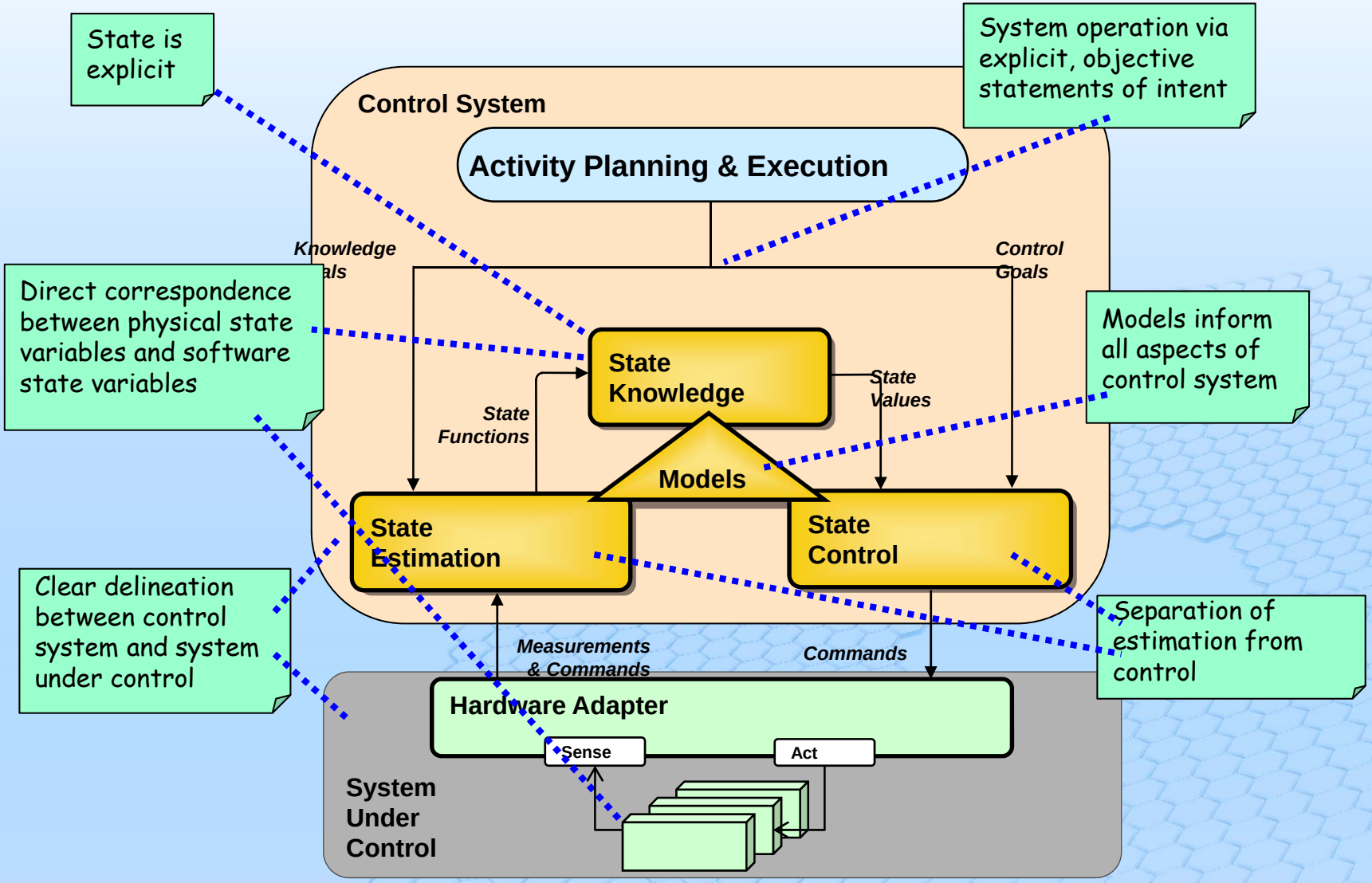
We see, not what is, but what we perceive — with a little help from our senses

Real world

Our actions are guided by what we expect them to do, given what we know

State Analysis – in a Nutshell

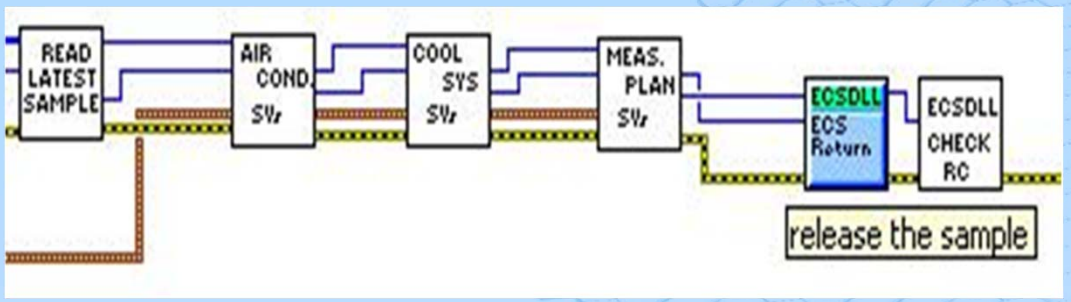
ESO
European Organisation for Astronomical Research in the Southern Hemisphere

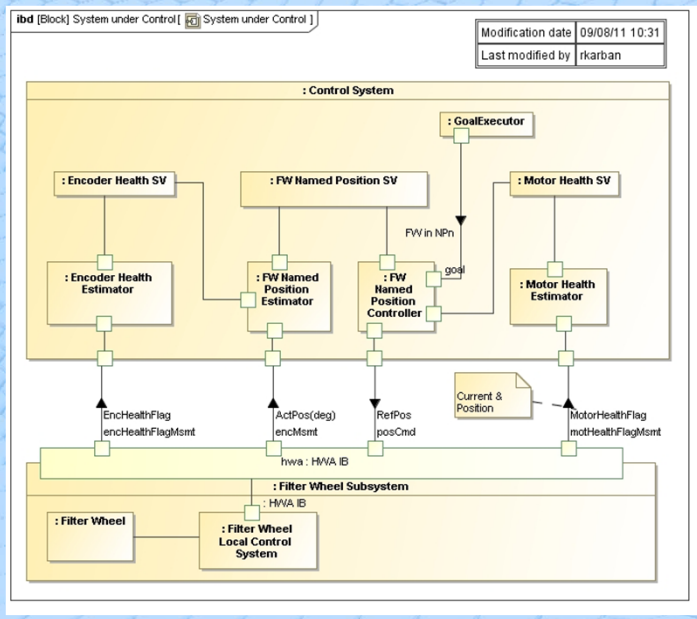


VLT Field Testing - Motivation

ESO
European Organisation for Astronomical Research in the Southern Hemisphere

- Test E-ELT technology decisions
- Refurbish VLT control system
- Operational Environment
- Apply State Analysis Method

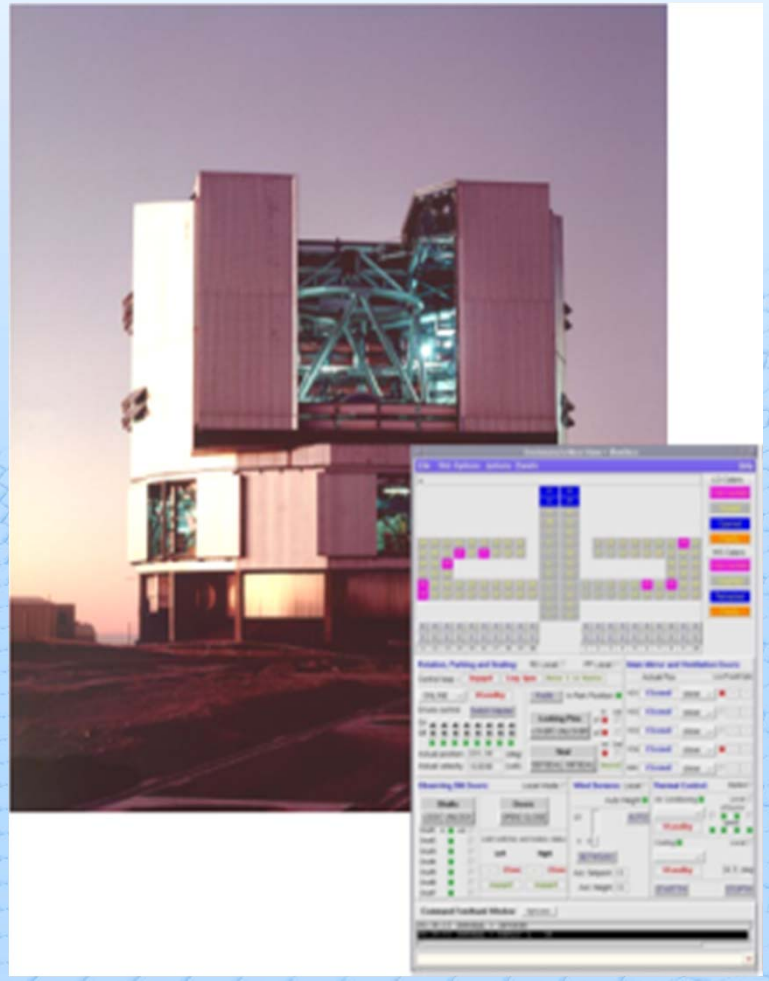




VLT Field Testing -Enclosure Control System Upgrade

ESO
European Organisation for Astronomical Research in the Southern Hemisphere

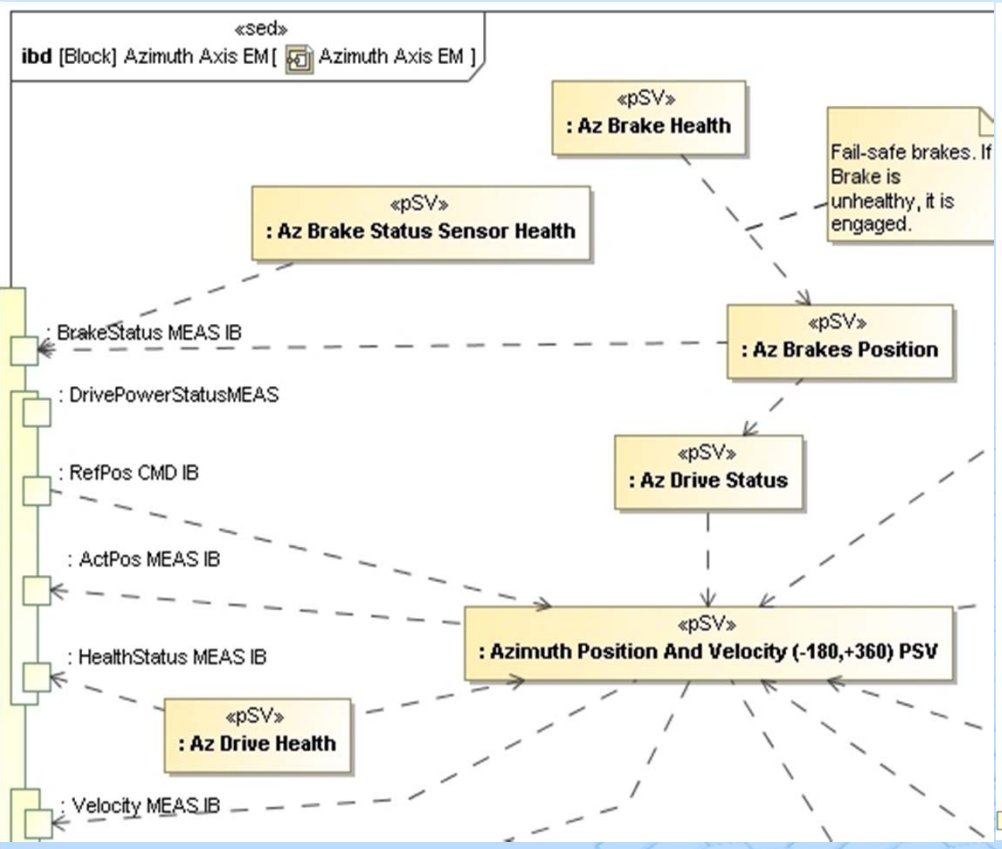
- 1500 I/O points (Dome, Windscreen, Louvers, etc)
- Interface to existing sensors and actuators
- Driven by SA Control Diamond
- Estimators implemented with LabView

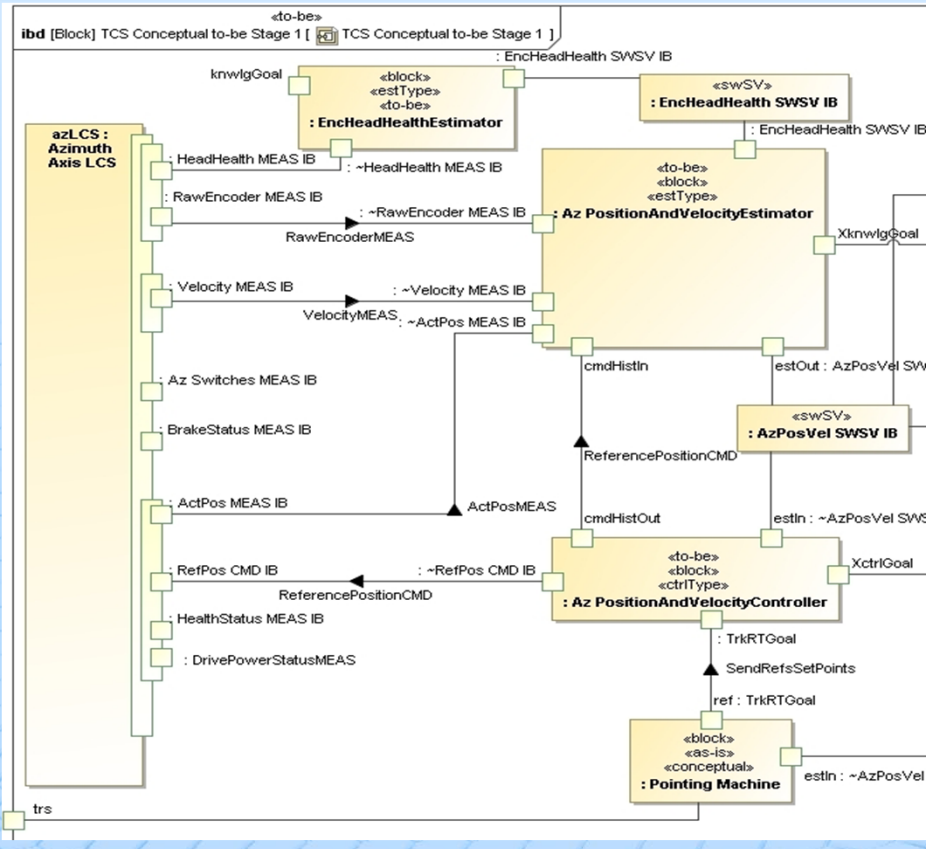


VLT Field Testing - Main axes Control System Upgrade

ESO
European Organisation for Astronomical Research in the Southern Hemisphere

- Provides all means for telescope positioning
- Apply more rigorously SA, integrated with OOSEM





Summary and Future Work

ESO
European Organisation for Astronomical Research in the Southern Hemisphere

- Summary
  - SA is built on sound theory
  - Guided by Architectural Principles and Rules
  - Confidence gained during VLT field tests
- Future Work
  - Collaboration between ESO and JPL
  - SA profile for SysML
  - Integration with MBSE practices