A Few Words First

Courtesy – Please mute your phone (*6 toggle)

Vote for Chapter Directors/Officers. Elections open now!

Oct 28-29 – Socorro Systems Summit – 2-Day Collaborative Workshop
Produced by Enchantment Chapter and New Mexico Tech

- **Date: Friday/Saturday, October 28-29.**
- **Place: New Mexico Tech, Socorro, NM.**
- **Fee: $100, faculty-selected students free.**
- **Keynote: INCOSE President-Elect Garry Roedler.**
- **8 collaborative workshops explore issues of mutual interest.**
- **See details on Chapter website, Library tab.**

Nov 9 – Ed Carroll, How is Model-based Systems Engineering Justified?

Dec 2 – Holiday Social, Savoy Bar & Grill, 5:30-8:30 pm, 3-course dinner, $20
Speaker: Jennifer Owen-White, Manager, Valle de Oro National Wildlife Refuge

SEP certification? Training by ***Certification Training International***, a PPI company.
Course details | Course brochure
2016 Course Schedule (close by, others available as well):
October 17-21 | Denver, CO | Find out more
October 31- November 3 | Las Vegas, NV | Find out more

First slide, not recorded but retained in pdf presentation.

And Now - Introductions

Enchantment Chapter Monthly Meeting

12 October 2016 – 9:00-10:15 am:

Testing of Autonomous Systems – Challenges and State of the Art

Phillipp Helle, Airbus (Germany)
philipp.helle@airbus.com

Abstract: Autonomous systems are on the rise. However, the challenge to test autonomous systems to ensure their safe and fault-free behaviour is not solved yet. This is especially critical when we consider the fact that autonomous systems are often safety-critical systems envisaged to interact with humans without explicit human supervision. This presentation points out why testing autonomous systems is such a challenge and provides an overview of the current state-of-the-art and state-of-practice. The gathered information is then condensed into guiding points for the way forward.

Download slides today-only from GlobalMeetSeven file library or anytime from the Library at www.incose.org/enchantment

NOTE: This meeting will be recorded

Today's Presentation

Things to Think About

How can this be applied in your work environment?

What did you hear that will influence your thinking?

What is your take away from this presentation?

Speaker Bio

Philipp Helle joined Airbus Group Innovations in 2003 and is currently a member of the team *Model-based Systems and Software Engineering*.

He studied linguistics and computer science and received his MA from the University of Hamburg.

Since 2005, he is actively involved in research concerning model-based systems engineering including model-based testing and model-based safety analysis and the deployment of these approaches in the Airbus Group business units.

Philipp is a member of GfSE, the German INCOSE chapter, and a certified Project Management Professional (PMP).

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Testing of Autonomous Systems - Challenges and Current State-of-the-Art

Philipp Helle

Airbus Group Innovations, TX4VI

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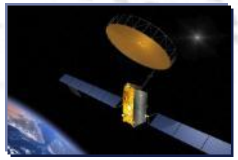
AIRBUS GROUP …at a glance

AIRBUS

AIRBUS HELICOPTERS

AIRBUS DEFENCE & SPACE



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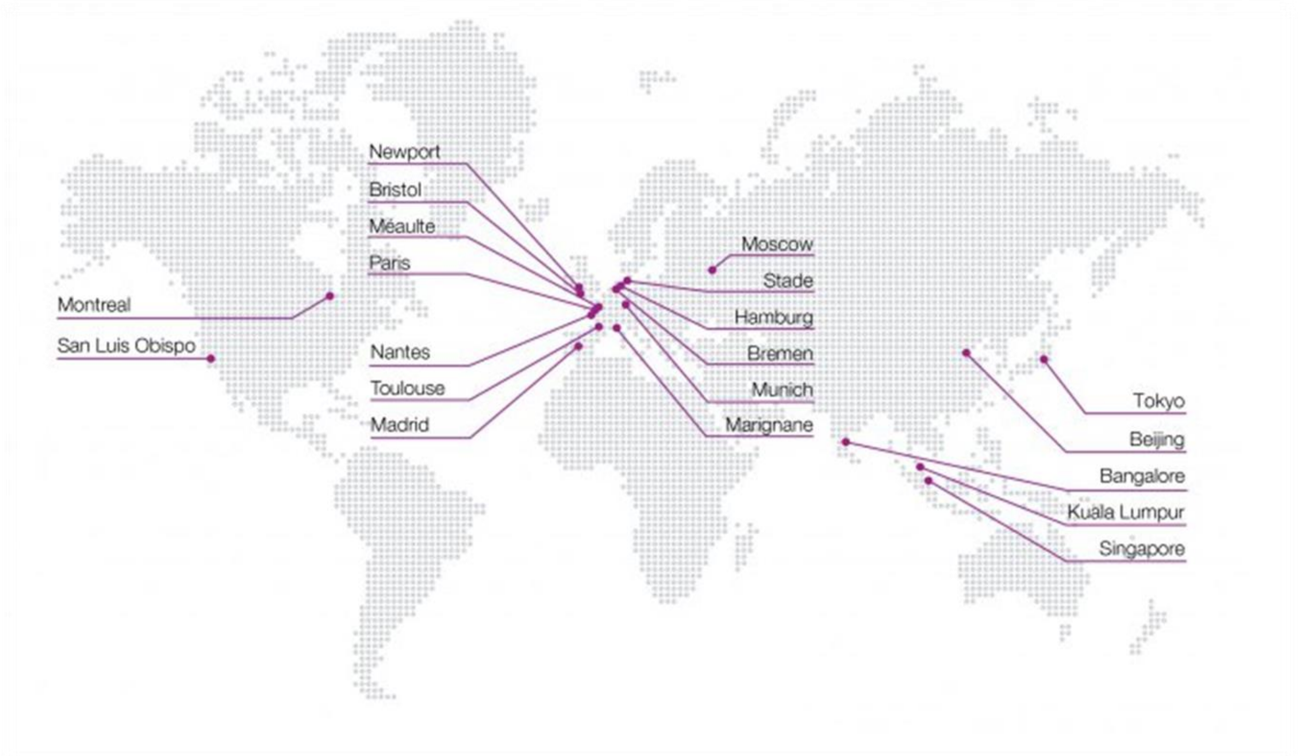
Airbus Group Innovations

Key figures

- Over 800 Researchers, Scientists, Engineers worldwide
- 20 sites around the world
- Located in 12 countries
- More than 100 new patent applications every year



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Outline

- Autonomous Systems
- Testing Autonomous Systems
- “Things to do”

Autonomous Systems

Autonomous systems










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Autonomous systems

- From *auto* = *self* and *nomos* = *law* -> self-governing

- "an autonomous system has free will" [1]

- Common characteristics
  - **Knowledge:** The system knows facts about itself and its surroundings.
  - **Adaptation:** The system can adapt its own behavior dynamically to cope with changing surroundings.
  - **Self-awareness:** The system can examine and reason about its own state.
  - **Emergence:** Simple system elements construct complex entities.

[1] Clough, B. T. (2002). Metrics, schmetrics! How the heck do you determine a UAV's autonomy anyway. Air Force Research Laboratory.

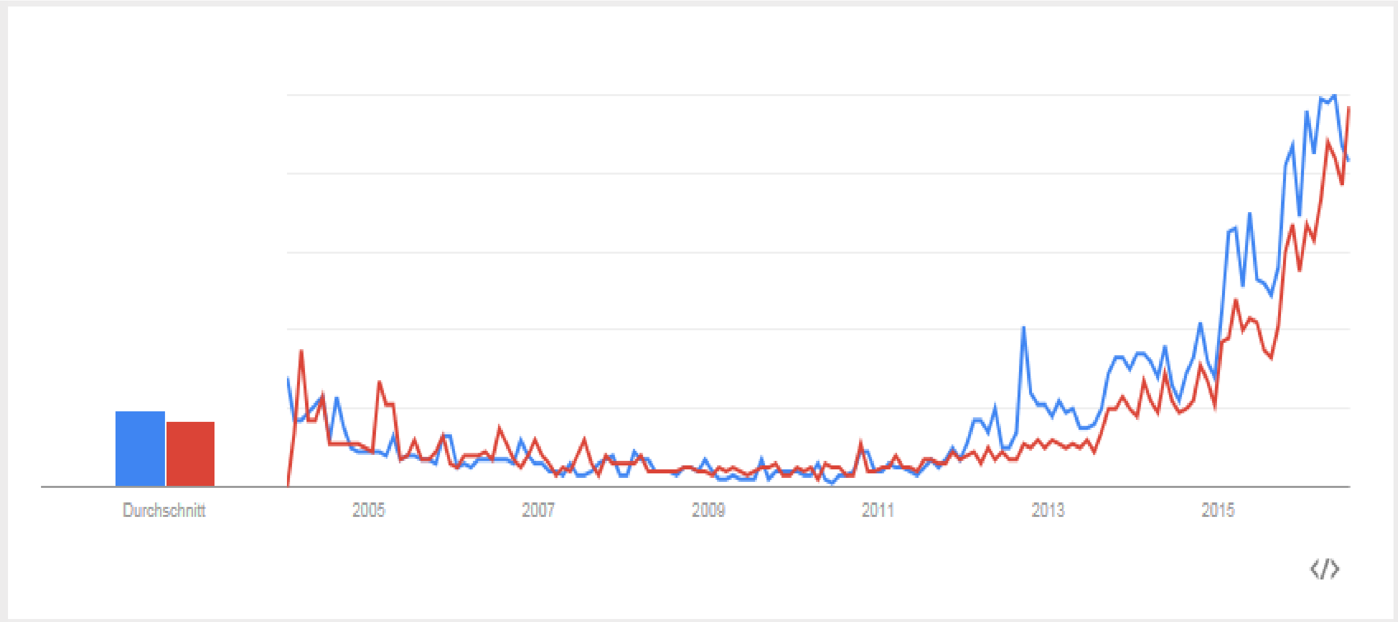
Autonomy levels

Clough [1] has created a taxonomy of UAVs based on the level of autonomy the system has called **Autonomous Control Level (ACL):**

- **Remotely Piloted** (ACL 1): The UAV is simply a remotely piloted aircraft with the human operator making all decisions.
- **Remotely Operated** (ACL 2-5): The human allows the UAV to do the piloting, but outer loop decisions are made by the human (like where to go and what to do once there). The UAV is a "mother-may-I" system, asking the human permission to do tasks.
- **Remotely Supervised** (ACL 6-9): The human allows the UAV to execute its own tasks, only taking command if the UAV fails to properly execute them.
- **Fully Autonomous** (ACL 10): The UAV receives goals from the humans and translates that into tasks which it does without human intervention. The UAV has authority to make all decisions.

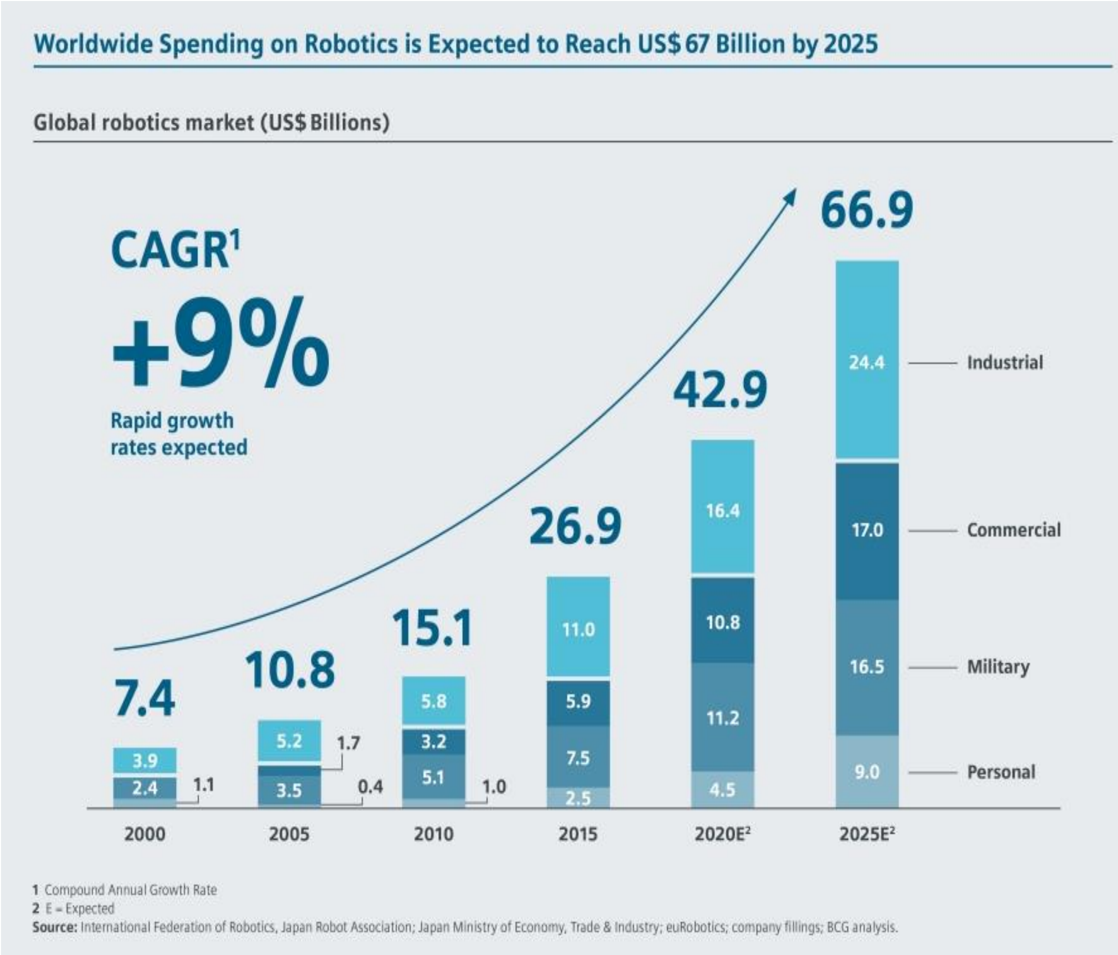
[1] Clough, B. T. (2002). Metrics, schmetrics! How the heck do you determine a UAV's autonomy anyway. Air Force Research Laboratory.

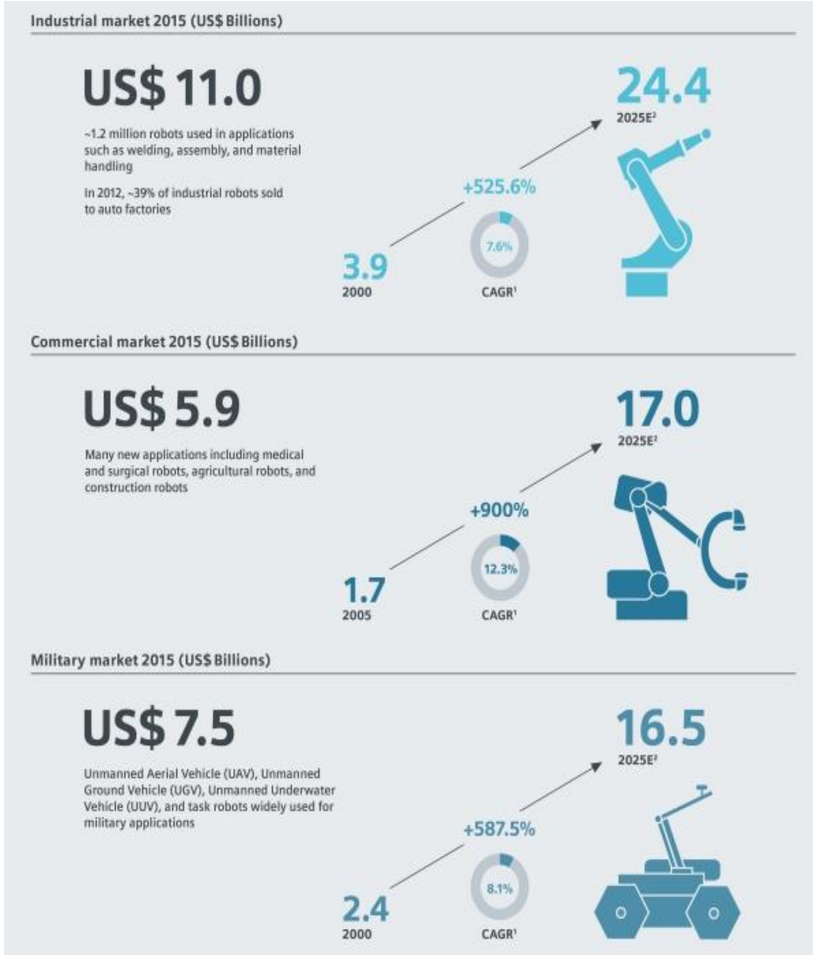
Trends



Autonomous cars
Autonomous driving

Numbers





Source: http://www.siemens.com/innovation/en/home/pictures-of-the-future/digitalization-and-software/autonomous-systems-infographic.html

Quotes

- “untapped short term market value of circa 7 billion per annum just for relatively low level autonomy products and services” [1]
- “potential economic impact of autonomous cars and trucks could be $200 billion to $1.9 trillion per year by 2025” [2]
- [they] estimate the total market for civilian robots at more than 10 billion euros in 2012 and continue that it ”should exceed 100 billion euros before 2020” [3]
- US DoD had planned to spend a $24 billion-plus total budget for unmanned systems in the 2007-2013 timeframe [4]

[1] Mallors, R. L. (2013). Autonomous systems: Opportunities and challenges for the UK. IET Seminar on UAVs in the Civilian Airspace.
[2] Manyika, J., Chui, M., Bughin, J., Dobbs, R., Bisson, P., & Marrs, A. (2013). Disruptive technologies: Advances that will transform life, business, and the global economy. McKinsey Global Institute San Francisco, CA, USA.
[3] Autefage, V., Chaumette, S., & Magoni, D. (2015). Comparison of time synchronization techniques in a distributed collaborative swarm system. European Conference on Networks and Communications (EuCNC) (pp. 455-459). IEEE.
[4] Clapper, J., Young, J., Cartwright, J., & Grimes, J. (2007). Unmanned systems roadmap 2007-2032. Office of the Secretary of Defense.

Testing Autonomous Systems

Testing autonomous systems

Is an unsolved issue:

- "testing autonomous systems is still an unsolved key area" [1]
- "the major barrier that prevents the USAF from gaining more capability from autonomous systems is the lack of V&V methods and tools" [2]
- "developing certifiable V&V methods for highly adaptive autonomous systems is one of the major challenges facing the entire field of control science, and one that may require the larger part of a decade or more to develop a fundamental understanding of the underlying theoretical principles and various ways that these could be applied" [2]
- "there is a common misconception in the testing industry that all unmanned autonomous systems can be tested using methodologies developed to test manned systems" [3]

[1] Weiss, L. G. (2011). Autonomous robots in the fog of war. IEEE Spectrum, pp. 30-57.
[2] Dahm, W. J. (2010). Technology Horizons a Vision for Air Force Science & Technology During 2010-2030. Office of the US Air Force Chief Scientist.
[3] Thompson, M. (2008). Testing the Intelligence of Unmanned Autonomous Systems. ITEA Journal, pp. 380–387.

Testing autonomous systems is hard

- **Complex environment**

Testing autonomous systems is hard

- **Complex environment**
- **Complex software**

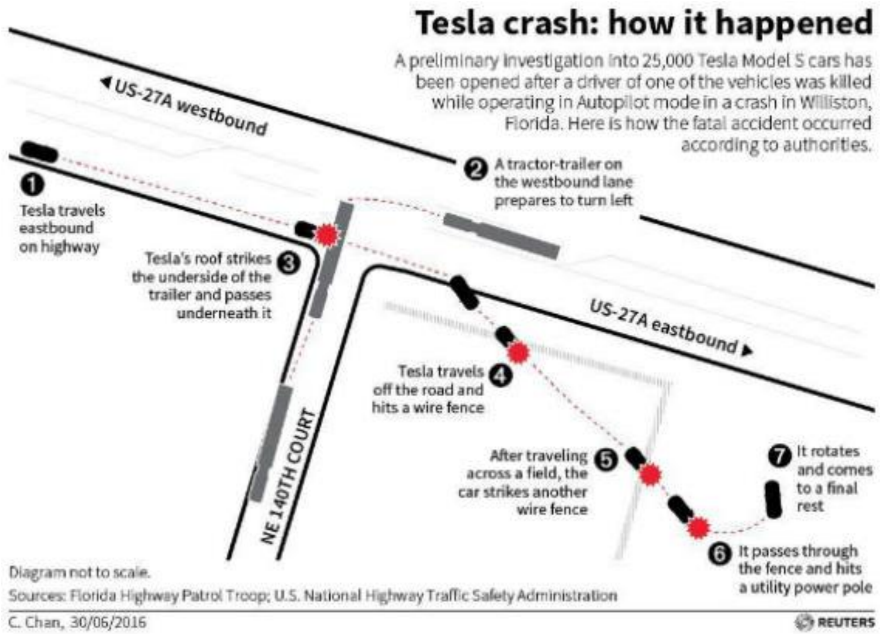
Testing autonomous systems is hard

- **Complex environment**
- **Complex software**
- **Non-deterministic behaviour**

Testing autonomous systems is hard

- **Complex environment**
- **Complex software**
- **Non-deterministic behaviour**
- **High expectations**

High expectations



"Society holds robots to a higher standard and has a lower tolerance for their errors."

Weiss, L. G. (2011). Autonomous robots in the fog of war. *IEEE Spectrum*, pp. 30-57.

Tesla Autopilot accident

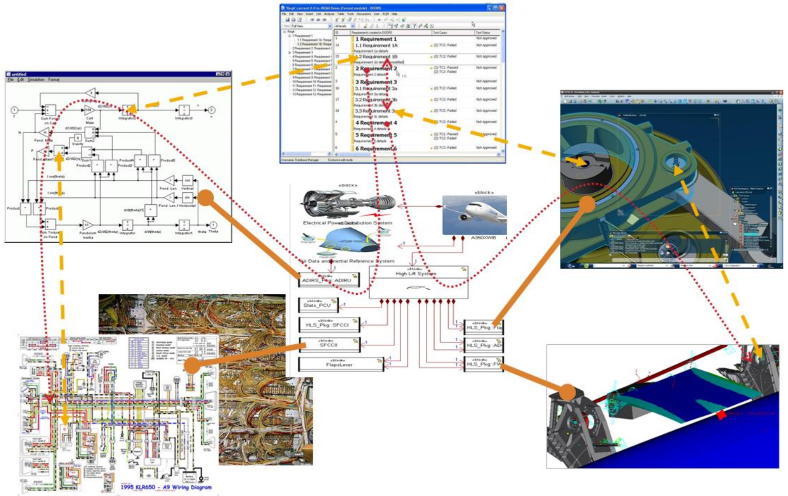
- Road traffic deaths USA 2015: ~ 30.000 (94 million miles per death)
- Death caused by "autonomous" cars: 1 (130 million miles per death)

“Things to do”

“Things to do”

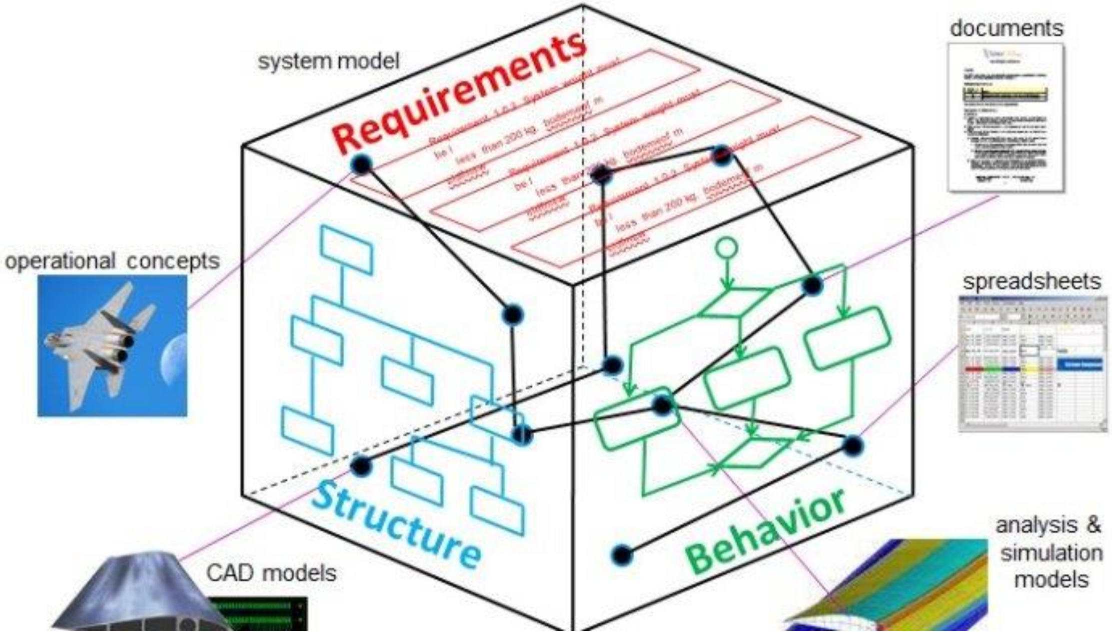
1.Use models

Use models



Model-based Systems Engineering (MBSE)

- can significantly reduce the number of defects that are introduced into a development project
- leads to consistent and unambiguous specifications
- enables early validation of system by simulation and analysis of design data by computers
- enables informed design trade-offs



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"Things to do"

1. **Use models**
2. **Be formal**

Be formal

Formal methods harness mathematical proofs and computer power for automatic reasoning

Formal verification / Model checking:

- Fully automatic and usually quite fast
- Allows the computer to check properties of a formal system model for the infinite set of possible scenarios
- The result of the computation is 100% reliable for the system model at hand
- Limited application due to restriction such as model complexity and discretization
  → however applications for autonomous systems and safety-critical artificial intelligence systems are still seriously considered (cf. program of NASA Formal Method Symposium 2016)

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“Things to do”

1. **Use models**

2. **Be formal**

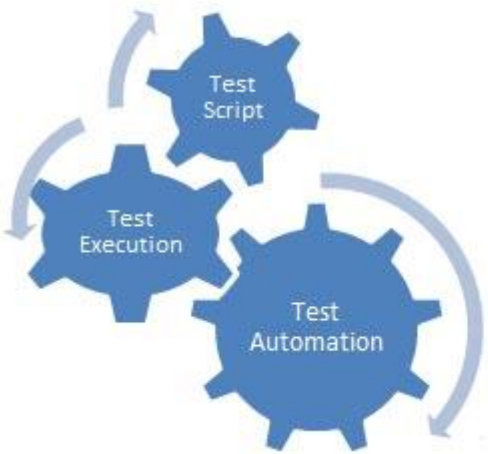
3. **Automate**

Automate

Test automation (test execution and test case generation)

- is critical for covering a larger test space
- reduces resources for regression testing
- enables test engineers to concentrate on their job

Statistical Model Checking combines automated formal performance checking with Monte Carlo simulations for scalability → capable to assess that certain properties are mathematically true up to a certain probability, even when the system is black box (already used in Systems of Systems projects where complex interactions between distributed/autonomous systems exist)



“Things to do”

1. **Use models**

2. **Be formal**

3. **Automate**

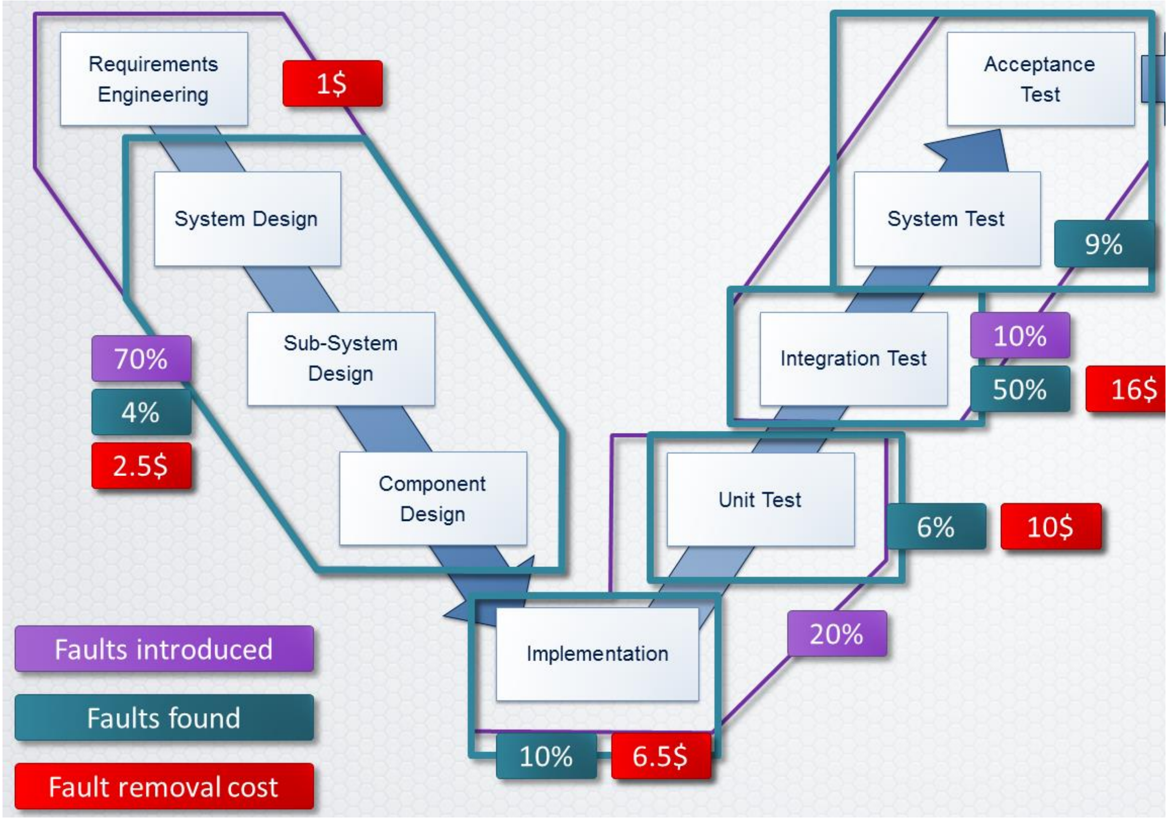
4. **Test early**

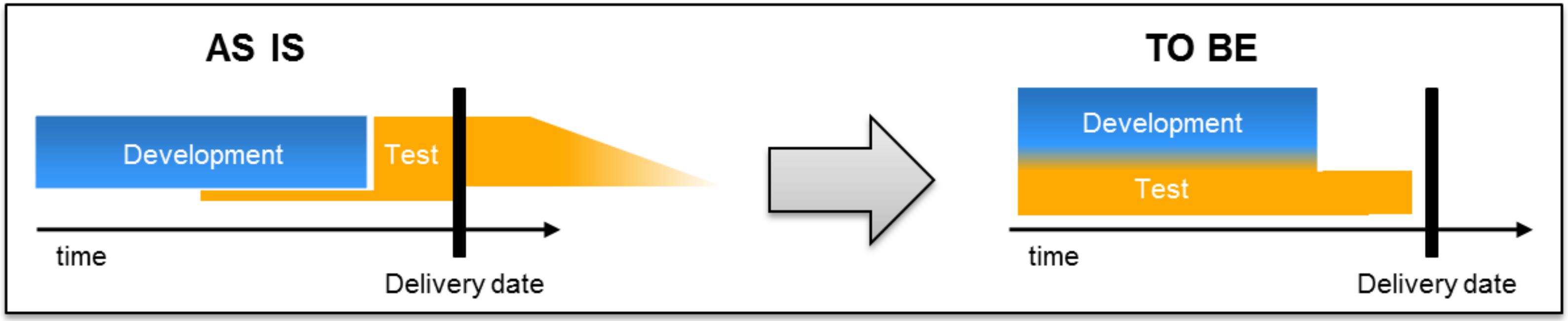
Test early

Early fault detection is paramount for keeping fault removal costs in check

Executable specifications enable development & testing in parallel

However, testing early is not enough for validating systems with online learning since their behaviour evolves in operation





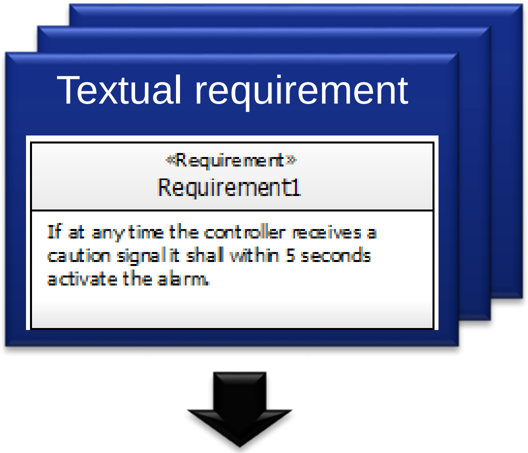
“Things to do”

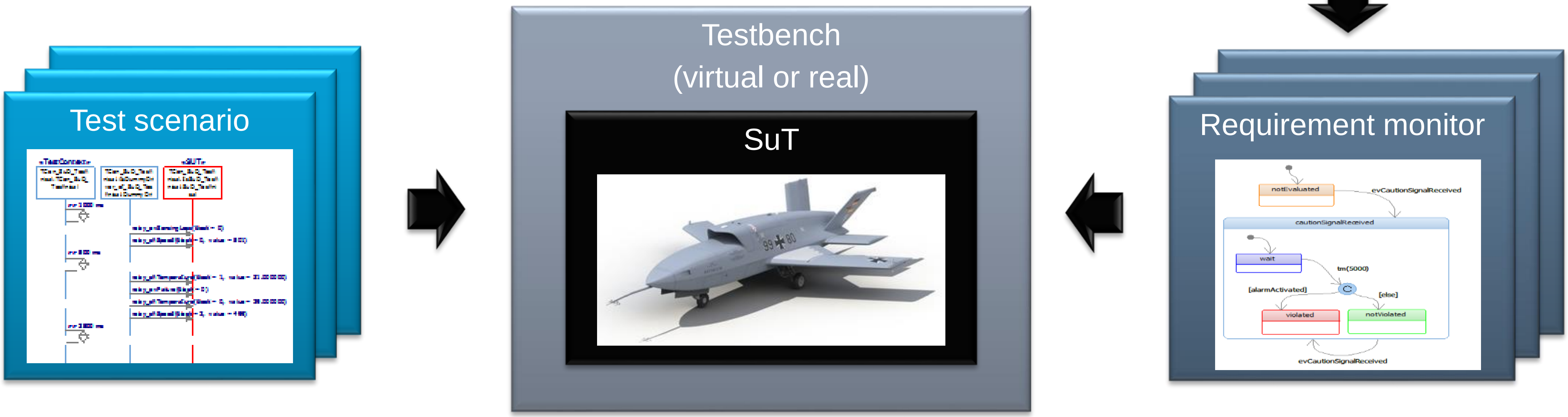
1. **Use models**
2. **Be formal**
3. **Automate**
4. **Test early**
5. **Test continuously**

Test continuously

Separation of test scenario and test verdict generation enables

- Continuous testing of requirements in all test scenarios
- Automatic test verdict generation
- Reuse of test monitors for virtual and real tests and runtime monitoring





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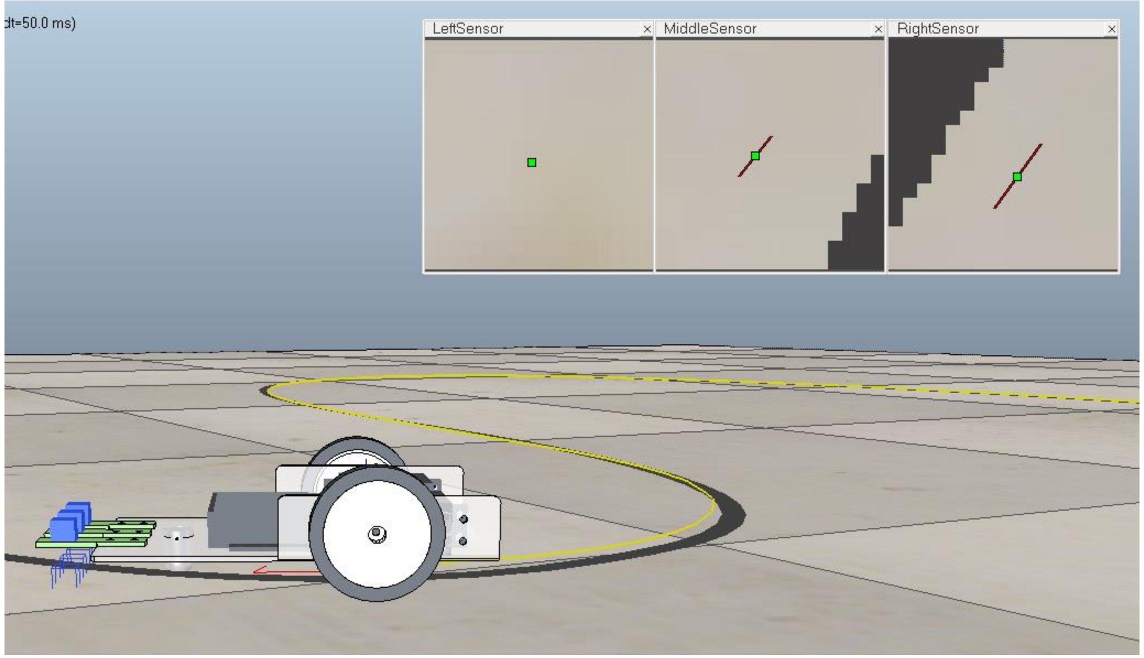
“Things to do”

1. **Use models**
2. **Be formal**
3. **Automate**
4. **Test early**
5. **Test continuously**
6. **Test virtually**

Test virtually



Virtual testing enables

- scalable testing through parallelisation
- early testing
- testing of unsafe/imperfect systems in safe virtual environments

(a) MR Components (b) Physical World (c) Virtual World (GAZEBO)

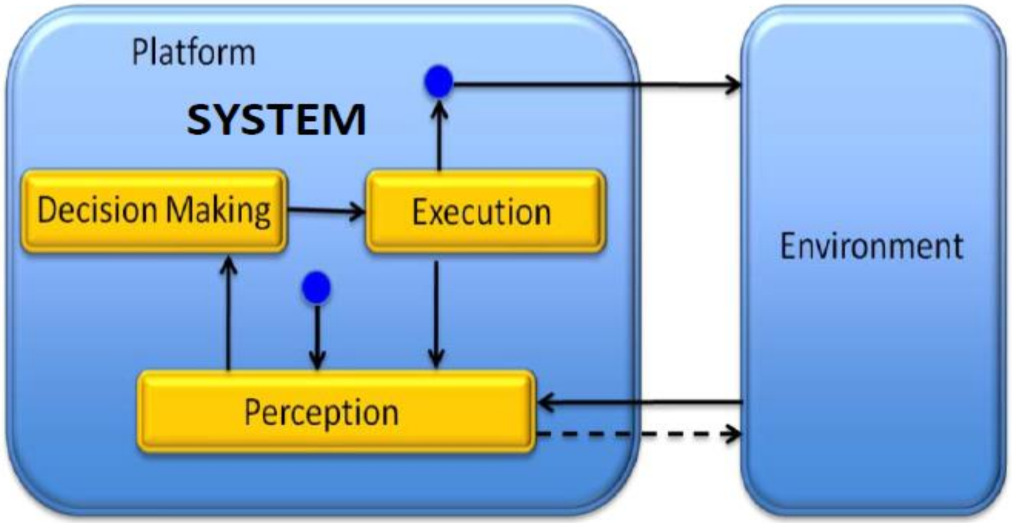
"Things to do"

1. **Use models**
2. **Be formal**
3. **Automate**
4. **Test early**
5. **Test continuously**
6. **Test virtually**
7. **Test smartly**

Test smartly

What to test?

- Perception function (semi tough),
- Decision making function (tough, requires adaptive testing methods),
- Execution/action function (traditional methods)



What to test for? [1]

- **Avoiding Negative Side Effects:** Avoid damage or disturbance without manually specifying and testing everything
- **Avoiding Reward Hacking:** Ensure that the system does not game its reward function
- **Robustness to Distributional Shift:** Ensure that the system behaves robustly, when in an environment different from its training environment

[1] Amodei, Dario, et al. "Concrete problems in AI safety." *arXiv preprint arXiv:1606.06565* (2016).

Thank you for your attention!

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Please

The link for the online survey for this meeting is

www.surveymonkey.com/r/enchant_10_12_16

www.surveymonkey.com/r/enchant_19_12_16

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Recording will be there library tomorrow.