APPLYING SAFETY AND SYSTEMS ENGINEERING PRINCIPLES FOR ANTIFRAGILITY

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Content

- Safety engineering and Safety Integrity Levels (SIL)
- Some issues with the SIL criterion
- Introducing the normative ARRL criterion
- Illustrated architectures
- ARRL and antifragility
- Autonomous traffic and ARRL-7
- Conclusions
- Note: Work In Progress!

Systems Engineering vs. Safety Engineering

- System = holistic
- Real goal is **"Trustworthy Systems"**
  - Cfr. Felix Baumgartner almost did not do it because he didn't trust his safe jumpsuit
- TRUST = by the user or stakeholders
  - Achieving intended Functionality
  - Safety & Security & Usability & Privacy
  - Meeting non-functional objectives
    - Cost, energy, volume, maintainability, scalability, Manufacturability,..
- So why this focus on safety?
- User expects guaranteed “QoS” from a “Trustworthy system”

Safety and certification

- **Safety** can be defined to be the **control of *recognized hazards*** to achieve an ***acceptable level** of **risk***.
  - Safety is general property of a system, not 100% assured
  - It is complex but there are moral liabilities
- Certification: In depth review => safe to operate
  - "Conformity assessment" (for automotive)
  - Not a technical requirement: confidence, legal
- **Evidence makes the difference:**
  - Evidence is a **coherent** collection of **information** that relying on a number of **process artifacts** linked together by their **dependencies and sufficient structured arguments** provides an **acceptable proof** that a specific system goal has been reached.

Categorisation of Safety Risks

Category	Consequence upon failure	Typical SIL
Catastrophic	Loss of multiple lives	4
Critical	Loss of a single life	3
Marginal	Major injuries to one or more persons	2
Negliglible	Minor injuries at worst or material damage	1
No consequence	No damages, user dissatisfaction	0

- SIL ≅ f (**probability of occurrence, severity, controllability**)
  - As determined by HARA
  - SIL goals ≅ Risk Reduction Factor
- Criteria and classification are open to interpretation

Problems with SIL definition

- Poor harmonization of definition across the different standards bodies which utilize SIL=> Reuse?
- Process-oriented metrics for derivation of SIL
- SIL level determines architecture (system specific)
- Estimation of SIL based on **reliability estimates**
  - System complexity, particularly in software systems, makes SIL estimation difficult if not impossible
  - based on probabilities that are very hard if not impossible to measure and estimate
  - Reliability of software (discrete domain) is not statistical!:
  - The **law of Murphy still applies**:
    - The next instant can be catastrophic

New definition: start from the component up

- **ARRL: Assured Reliability and Resilience Level**

ARRL 0	it might work (use as is)
ARRL 1	works as tested, but no guarantee
ARRL 2	works correctly, IF no fault occurs, guaranteed no errors in implementation) => formal evidence
ARRL 3	ARRL 2 + goes to fail-safe or reduced operational mode upon fault (requires monitoring + redundancy) - fault behavior is predictable as well as next state
ARRL 4	ARRL 3 + tolerates one major failure and is fault tolerant (fault behavior predictable and transparent for the external world). Transient faults are masked out
ARRL 5	The component is using heterogeneous sub-components to handle residual common mode failures

ARRL: what does it mean?

- **Assured:**
  - There is verified, trustworthy **evidence**
  - Process related and architecture related
- **Reliability:**
  - In absence of faults, MTBF is >> life-time: **QA aspects**
- **Resilience:**
  - The fault behaviour is predicted: **trustworthy behaviour**
  - Capability to continue to provide core function
- **Level**: ARRL is **normative**
  - Components can be classified: **contract**

Consequences

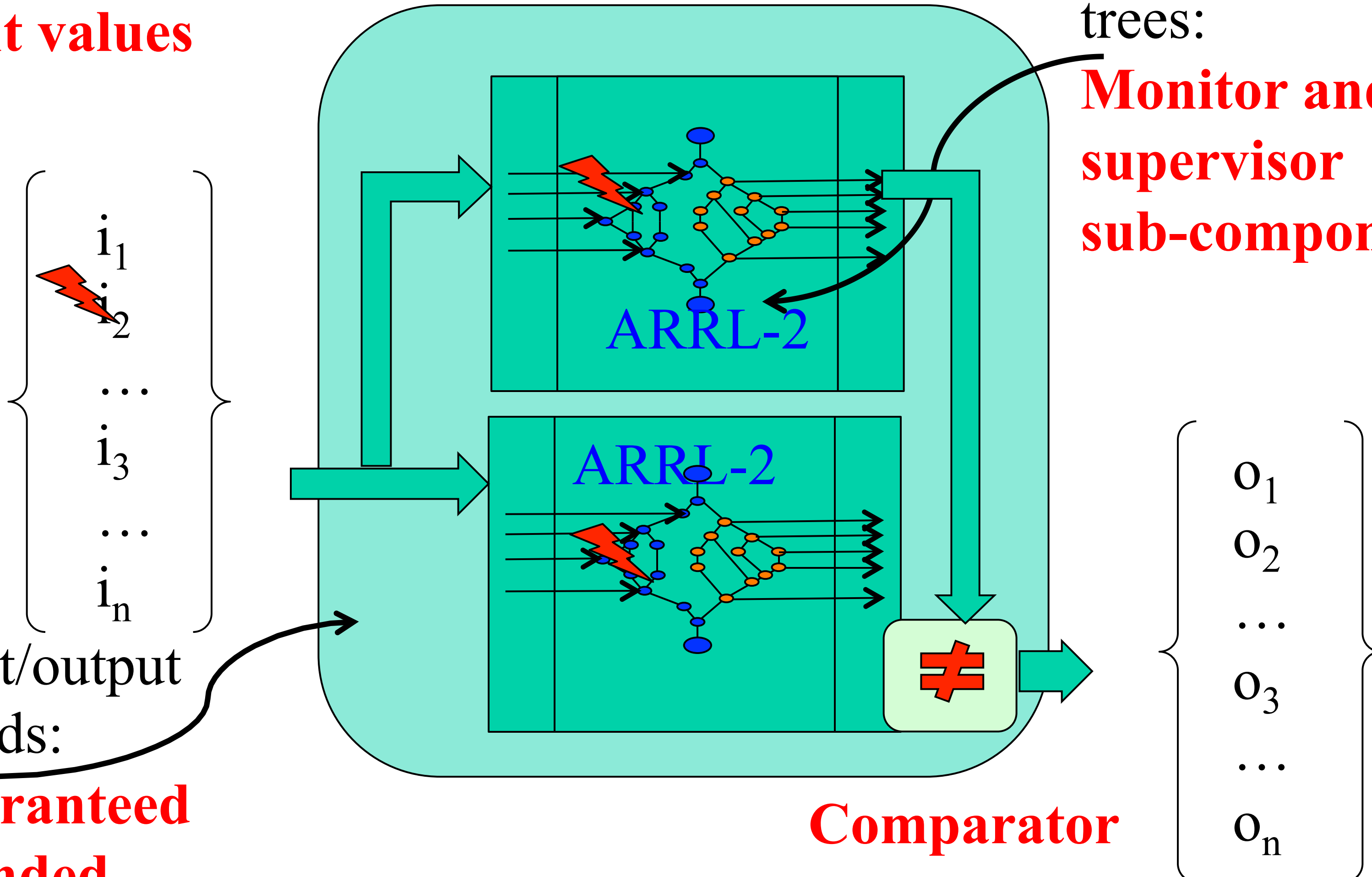
- If a system/component has a fault, it drops into a degraded mode => lower ARRL
  - ARRL3 is the operational mode after an ARRL4 failure
    - Functionality is preserved
    - Assurance level is lowered
- SIL not affected and domain independent
  - System + environment + operator defines SIL
- ARRL is a **normative criterion**:
  - Fault behavior is made explicit: verifiable
  - Cfr. IP-norm (comes with a predefined test procedure)

ARRL-3

Unanticipated input values

Induced fault

One or more state space trees:
Monitor and supervisor sub-component



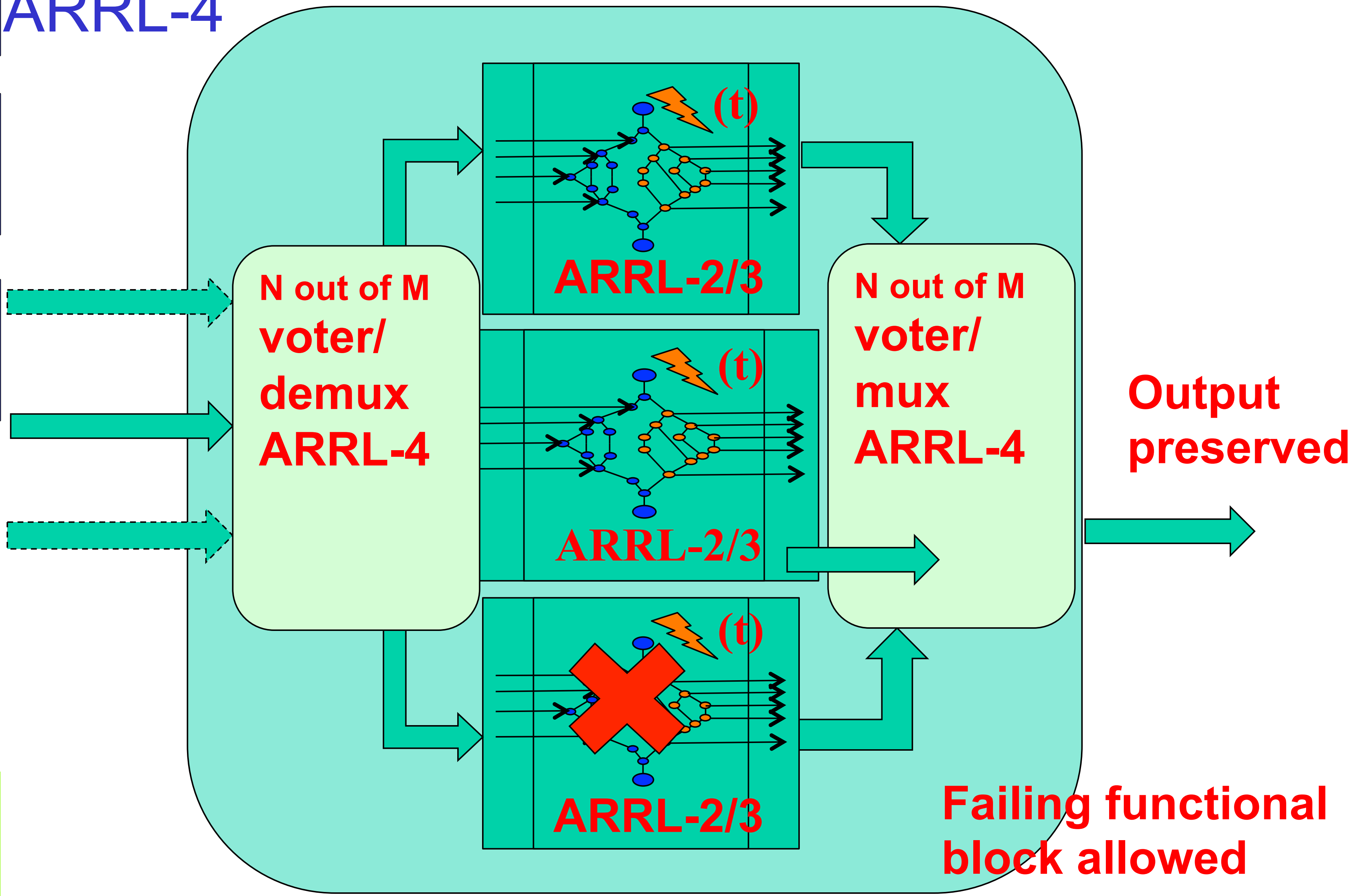
Input/output guards:
Guaranteed bounded

Comparator

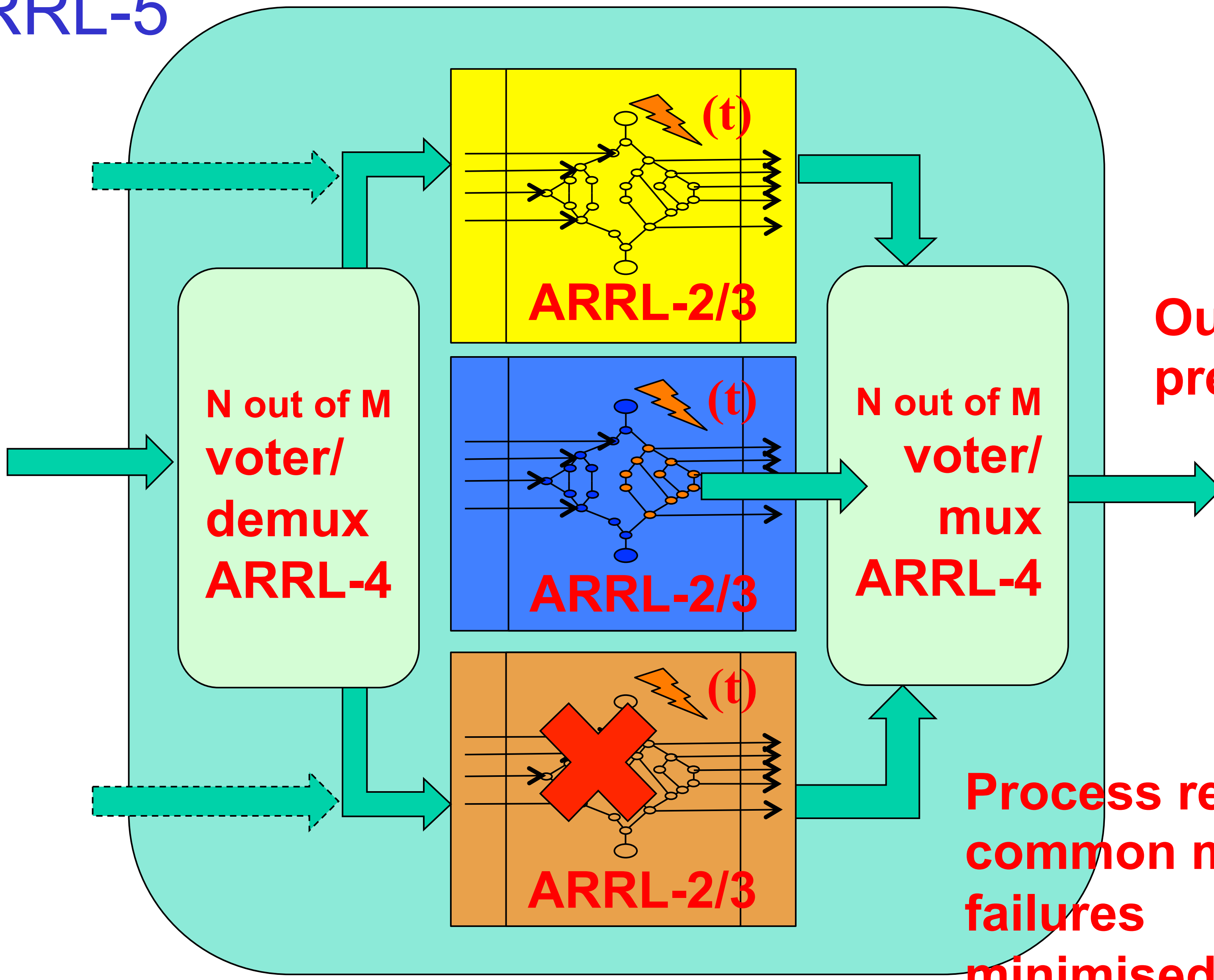
Fail safe output

Common mode failures possible

ARRL-4


N out of M
voter/
demux
ARRL-4
(t)
ARRL-2/3
(t)
ARRL-2/3
(t)
ARRL-2/3
N out of M
voter/
mux
ARRL-4
Output
preserved
Failing functional
block allowed

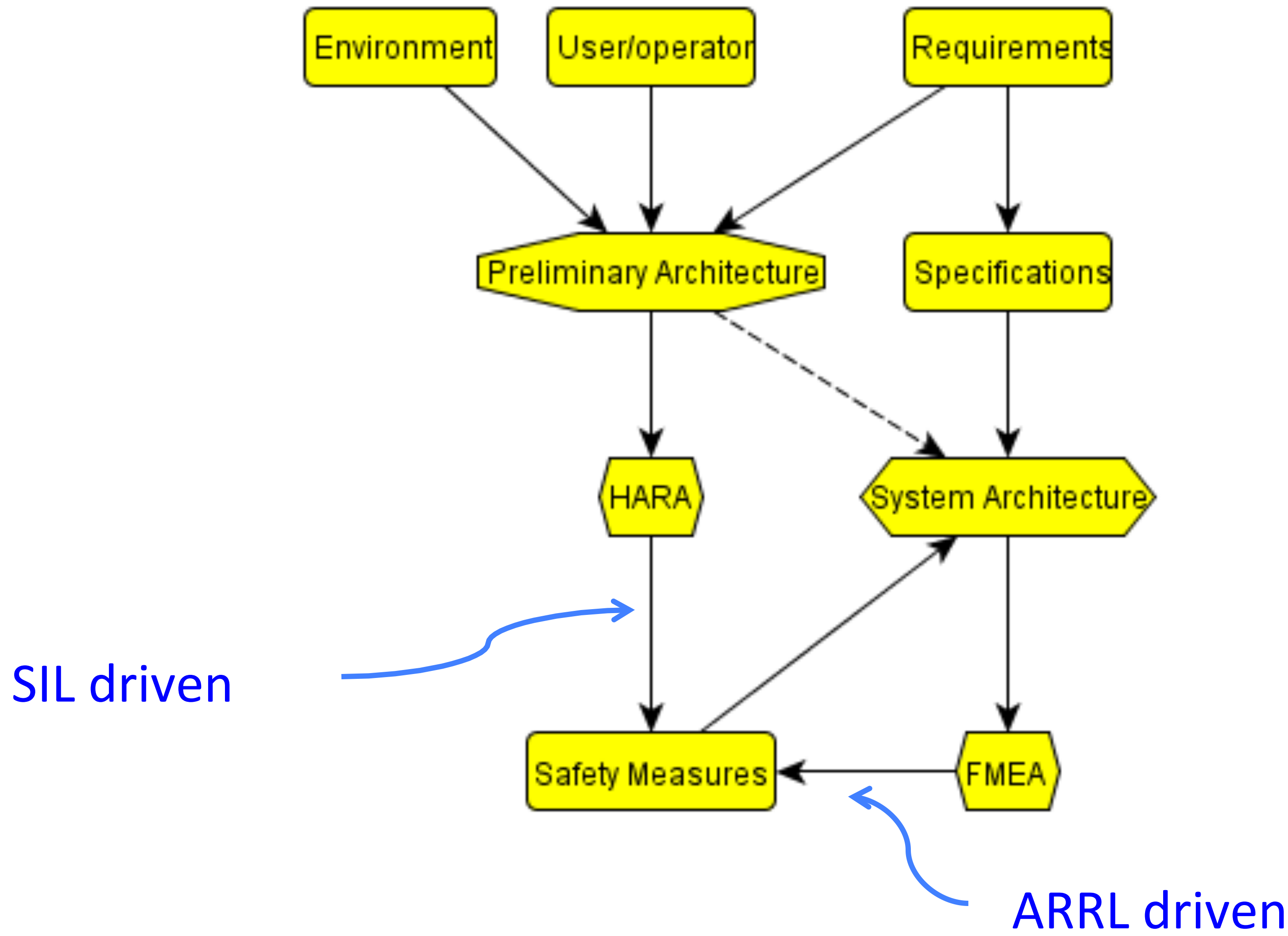
ARRL-5



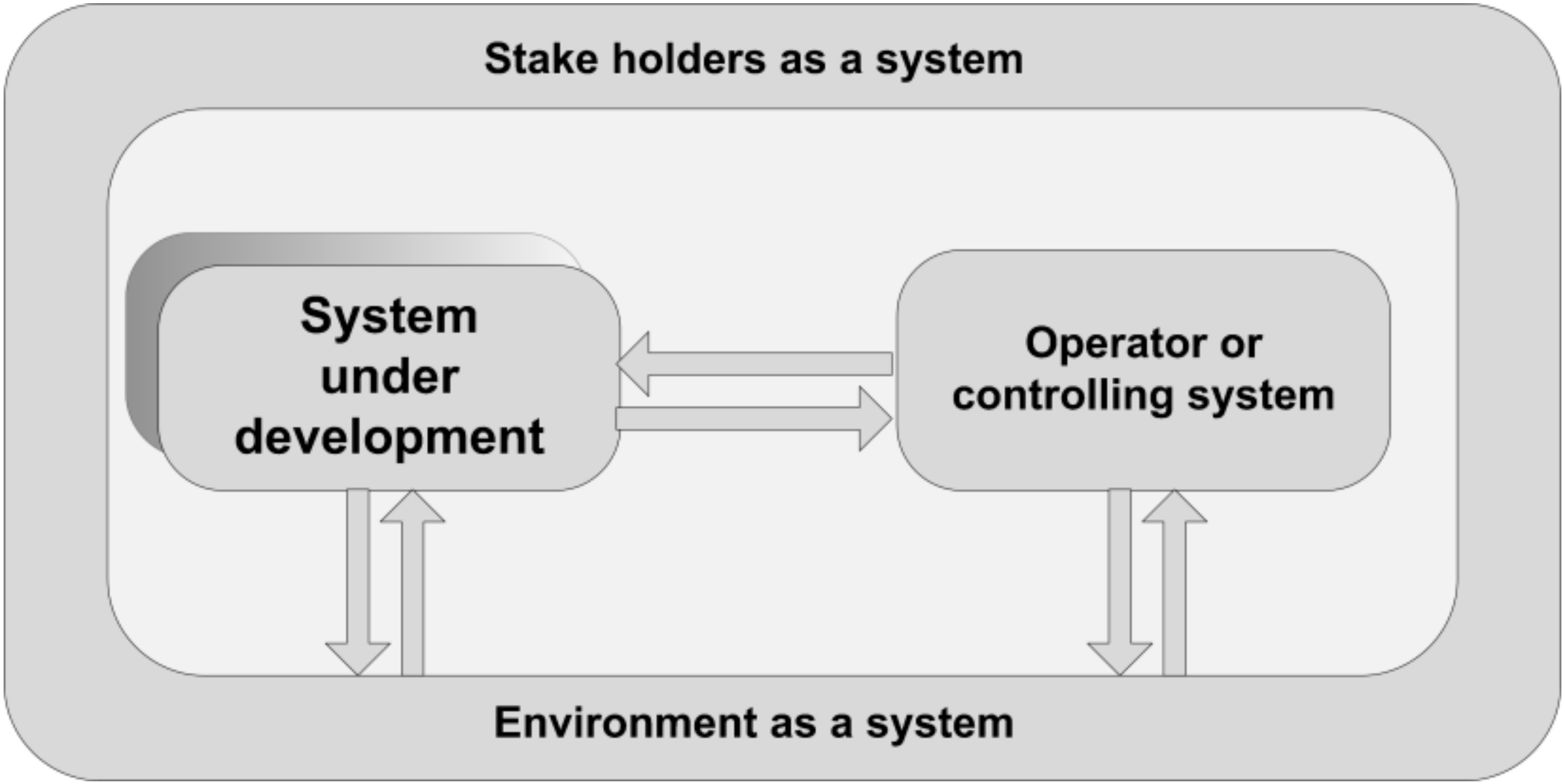
Output preserved

Process related common mode failures minimised

SIL and ARRL are complementary



A system is never alone



What means “anti-fragile”?

- New term quoted by Taleb
- An anti-fragile system gets “**better**” after being exposed to “**stressors**”
  - Better: we need a **metric** => QoS?
  - Stressors: cfr. **hazard, faults**, …
  - The issue in safety: **rare events** (improbable a priori, certain post factum) (Taleb’s “black swan”
- **What does it mean** in the context of safety/ systems engineering? Isn’t ARRL-5 not the top level?

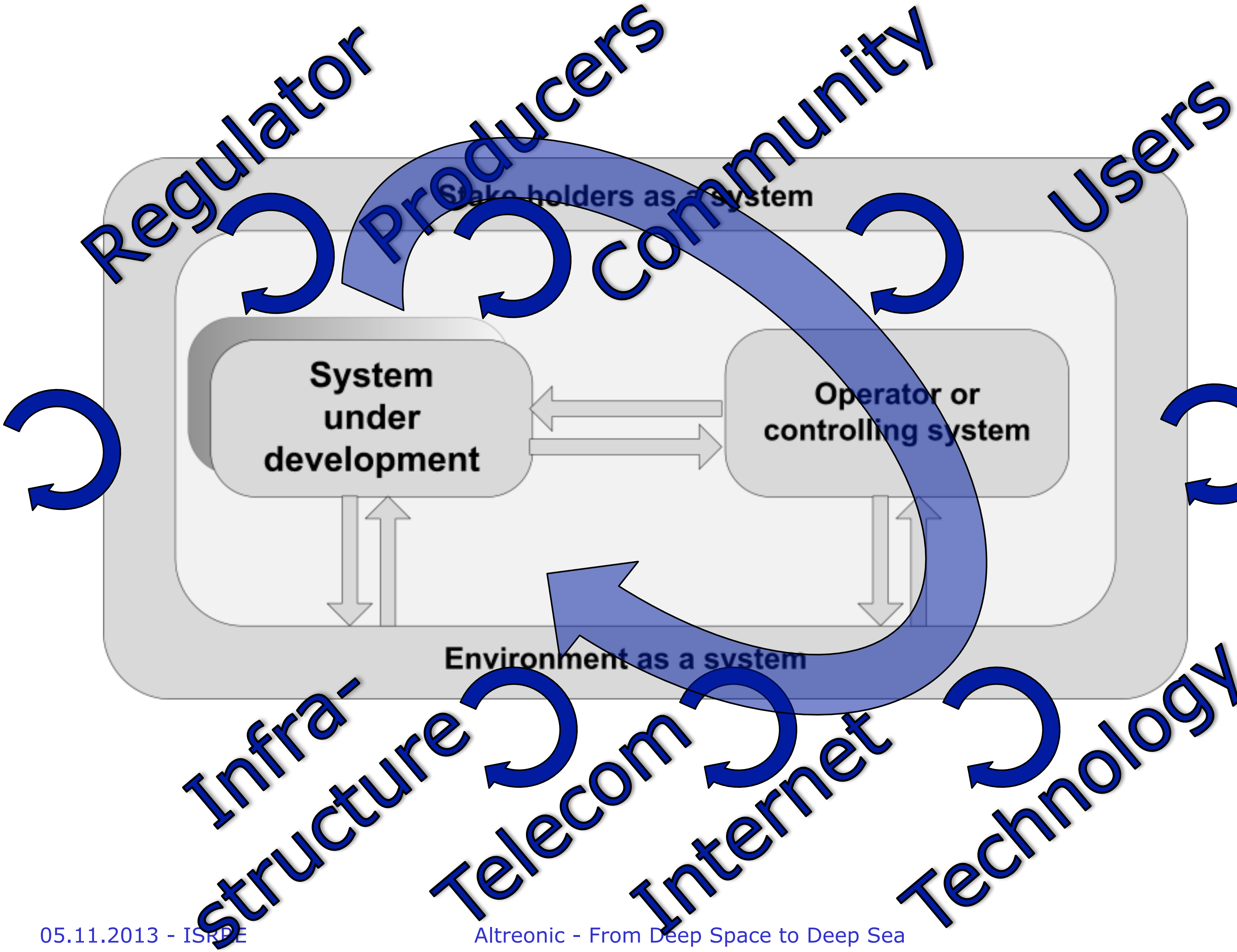
Two example domains

- **Automotive**:
  - 1,2 millon people killed/year: **daily event**
  - Cars get better, but people get killed: safer? QoS?
- **Aviation**:
  - 500 people killed/year: **a rare event**
  - Planes get better, cheaper, safer, energy-efficient
- Railway, telecommunications, medical, …
  - Similar examples
- **What sets them apart?**

Assessment in terms of ARRL

- **Automotive**:
  - Vehicle is a **ARRL-3 system**
  - Upon fault, presumed to go the fail-safe state
  - No black box, no records, …
  - Automotive is **a collection of vehicles**
- **Aviation**:
  - Planes are ARRL-5
  - Upon fault, redundancy takes over
  - Black box, central database,
  - Preventive maintenance
  - Aviation is **an eco-system**

Extended systems (of systems) view



Preconditions for anti-fragility

- **Extensive domain knowledge**: experience
- **Openness**: shared critical information
- **Feedback loops** at several levels between large number of stakeholders
- Independent **supervision**: guidance
- Core components are **ARRL-4 or -5**
- **The system is the domain**
- **Service matters more** than the component

ARRL-6 and ARRL-7 (inherits ARRL-5)

ARRL 3	ARRL 2 + goes to fail-safe or reduced operational mode upon fault (requires monitoring + redundancy) - fault behavior is predictable as well as next state
ARRL 4	ARRL 3 + tolerates one major failure and is fault tolerant (fault behavior predictable and transparent for the external world). Transient faults are masked out
ARRL 5	The component is using heterogeneous sub-components to handle residual common mode failures
ARRL 6	The component (subsystem) is monitored and a **process** is in place that maintains the system's functionality
ARRL 7	The component (subsystem) is art of a **system of systems** and a **process is in place** that includes continuous monitoring and improvement supervised by an **independent regulatory body**

Autonomous traffic

- Self-driving cars are the future? Cfr. Google car
- Systems engineering challenge much higher than flying airplanes
- Huge impact: socio-economic “black swan”
- Pre-conditions:
  - Vehicles become ARRL-5
  - System = traffic, includes road infrastructure
  - Standardisation (vehicles communicate)
  - Continuous improvement process
- Hence: needs ARRL-7

Beyond ARRL-7

- Not all systems are engineered by humans
- Biological systems:
  - Survivability (selection) and adaption
  - Build-in mechanism (long term feedback loops)
  - ARRL-8 ?
  - Inheritance of ARRL-7 ?
- Genetic engineering:
  - Directed selection and adaptation
  - ARRL-9? Or ARRL-7 with bio-components?

Conclusions

- ARRL concept allows compositional safety engineering with reuse of components/subsystems
- More complex systems can be safer
- A unified ARRL aware process pattern can unify systems and safety engineering standards
- ARRL-6 and ARRL-7 introduce a system that include a **feedback loop process during development but also during operation**

- **ANTIFRAGILE = ARRL-7**

More info:

www.altreonic.com

Further work

- Making ARRL normative and applicable
  - Refinement and Completeness of criteria
  - Normative: components carry contract and evidence
    - Independent of final use or application domain
    - Process evidence + validated properties
    - ARRL-3 and higher: HW/SW co-design?
  - Study link with a system's critical states
  - Apply it on real cases
- Input and feedback welcome