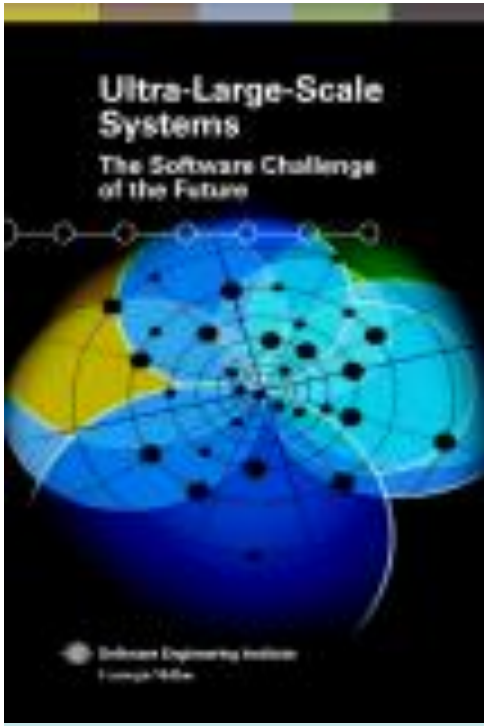
THALES

Design principles for Ultra-Large-scale Systems

Hillary Sillitto, ESEP
Thales UK

Ultra-Large Scale Systems

- *Ultra-large-scale (ULS) systems will be interdependent webs of software-intensive systems, people, policies, cultures, and economics.*
  - sheer scale changes everything.
  - decentralized
  - wide variety of stakeholders with conflicting needs
  - evolving continuously
  - constructed from heterogeneous parts.
  - people will be elements of the system
  - failure will be “normal””
- "Given the issues with today’s software engineering, how can we build the systems of the future that are likely to have billions of lines of code?”
- http://www.sei.cmu.edu/uls/



***Ultra-Large-Scale Systems**: The Software Challenge of the future*
Study Lead: Linda Northrop
Author Team
Peter Feiler
Richard P. Gabriel
John Goodenough
Rick Linger Tom Longstaff
Rick Kazman Mark Klein
Linda Northrop Douglas Schmidt
Kevin Sullivan Kurt Wallnau
***Chief Editor*: Bill Pollak**

INCOSE
International Council on Systems Engineering

THALES

- Part of LSCITS (Large Scale Complex IT Systems) research programme
- Briefs from Linda Northrop, Erik Hollnagel
- Key discussion points:
  - Practice ahead of science
    - "composing" systems we don't know how to analyse
  - Interdisciplinary and multi-disciplinary
    - need to engage diverse fields of knowledge
  - Wide range of practice between best and worst
    - academics can't get a clear view of "best practice"
  - Current certification techniques don't transfer readily to open systems

Traditional Systems and SW Engineering methods "not sufficient and may not even be appropriate"

Structure of paper

5 key issues

- Complexity
- Emergence
- People in the system
- Constant reconfiguration and evolution
- Organisations that develop, buy and use the systems

10 principles

- ULSS is a wicked problem
- Stability margin
- Value adding, opportunity seeking
- Node and web architecture
- Layered architecture
- Align to common purpose at multiple levels
- Understand & manage vulnerabilities
- Focus on phase transitions
- Provide feedback relevant to decision cycles and available choices
- Stable intermediate forms

5 practices

- Physical architecture:
- Functional architecture:
- Synchronise effects with control levers
- Analysis and responsibility boundaries
- Effective and appropriate measurement

Analogies in other domains

Town planning; Economics; Military; Physics; Chaos and complexity theory

Subjective and Objective complexity:

Is this real?

	subjective	objective
problem	**Subjective Complexity** exists in the mind of the observer. Primary indicator is the range of "Spreadthink" or "Weltanschaung" – the mismatch between different stakeholders' perceptions of key issues and priorities	**Objective Complexity** - exists in the problem situation and/or the system solution - is objectively measurable. Indicators are: 1. The number of variables and dimensions required to describe the system and its behaviour; 2. Our ability or otherwise to predict future state based on a) current state; b) history
solution		

3. Non-gaussian statistics???

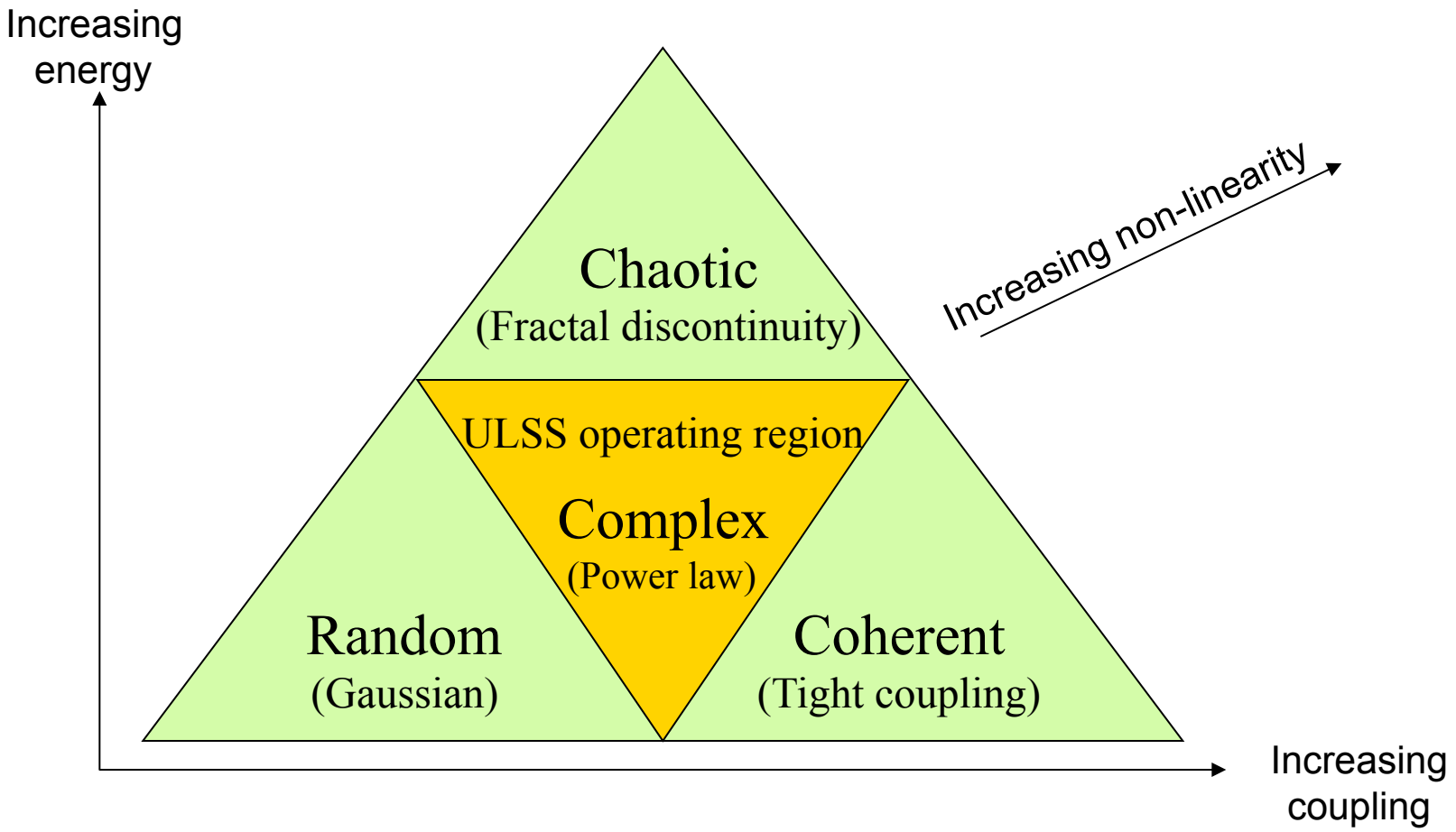
3 assertions

1. Objective complexity exists in technical systems
   - Will prove with example of optical partial coherence

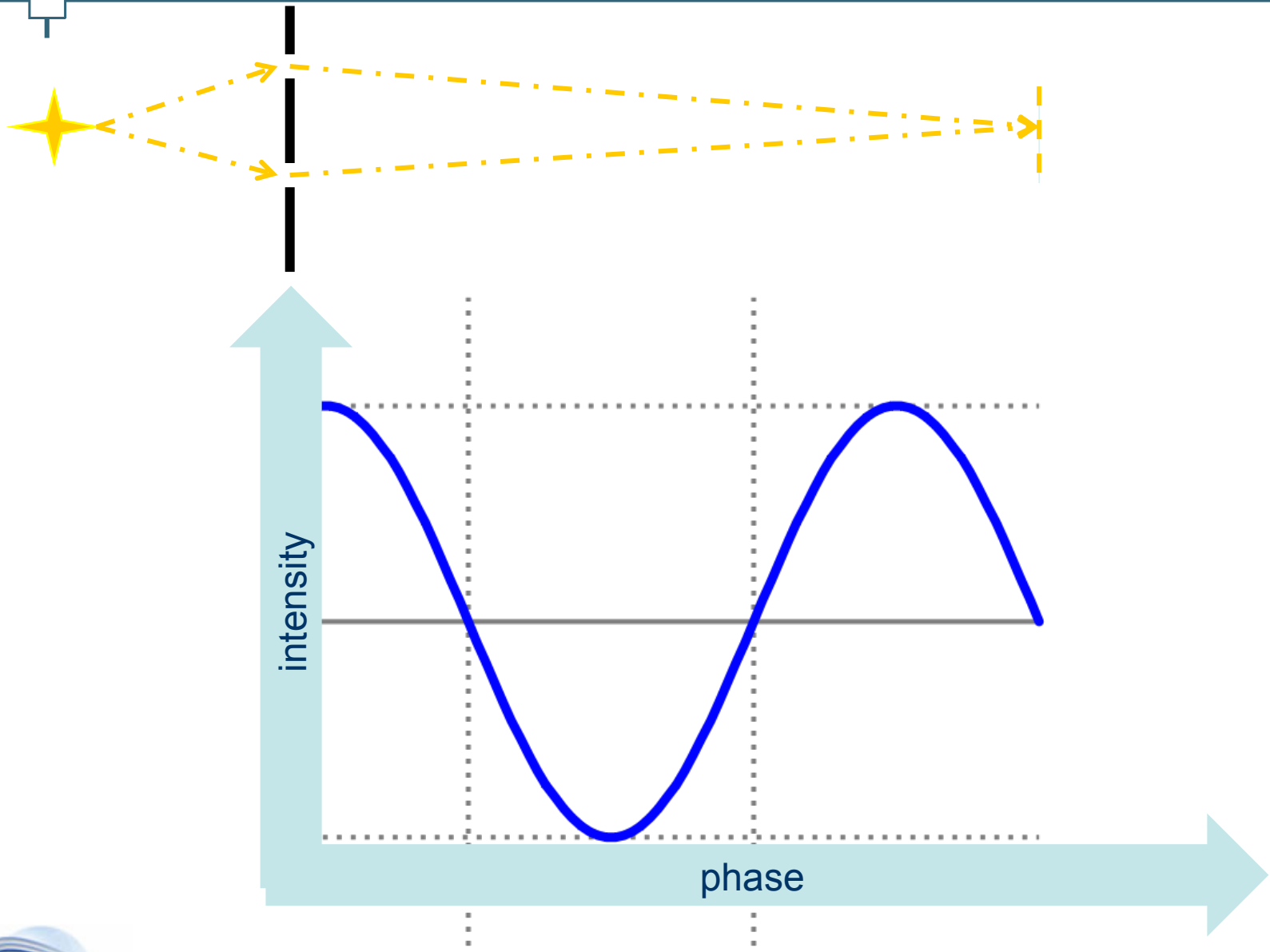
2. An objective aspect of complexity may exist in socio-technical systems
   - Property of the system not the observer
   - Distinct from Warfield's "subjective complexity"

3. If Power Law behaviour is observed, then you need to change your risk management perspective
   - This may be an objective measure of sociotechnical complexity!

Complexity: "Complex systems evolve to the edge of chaos"



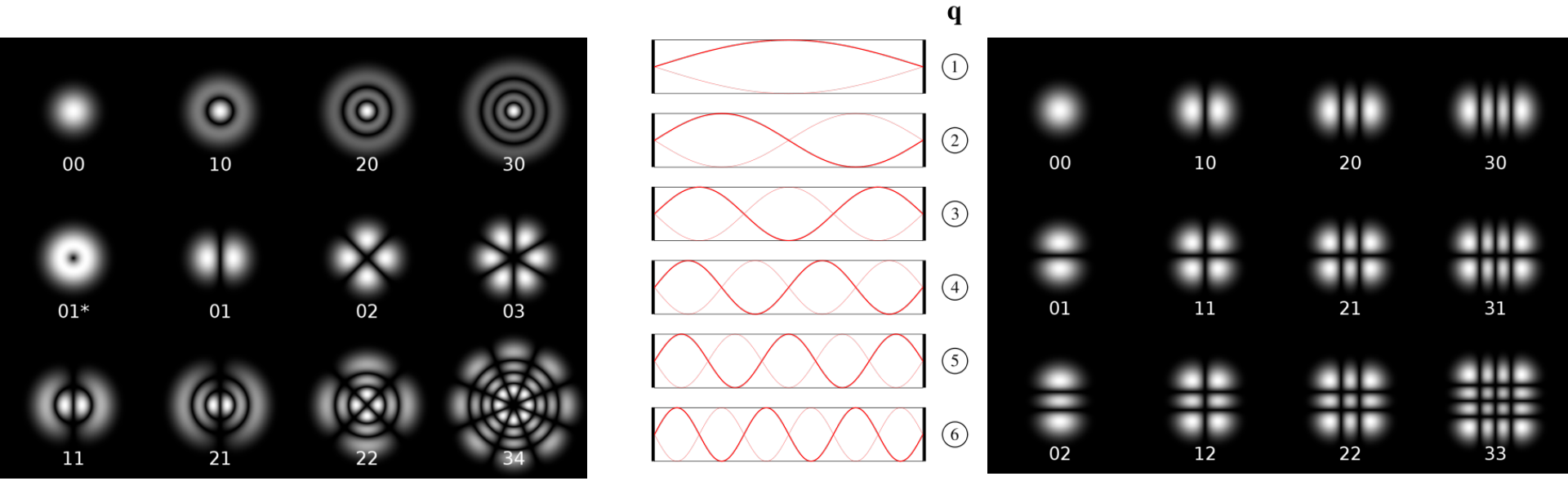
Non-linearity – interference of light waves



http://www.aaroncake.net/forum/uploaded/eng.zahir/2008551448_sine_wave.png

Complexity in optics: laser modes

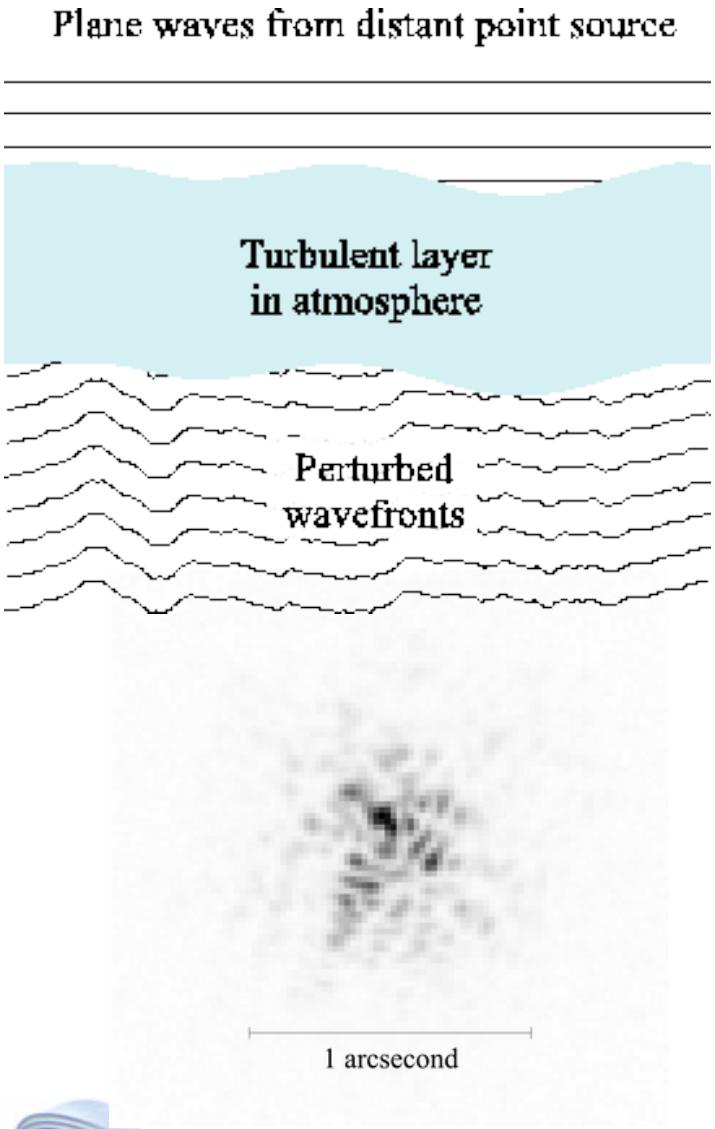
Coherence: light waves “march in step” in a laser cavity



Onset of Objective Complexity:

higher order transverse modes are mathematically predictable

Complexity in Optics: atmospheric distortion



We can model “typical” images of stars through turbulent atmosphere

http://www.youtube.com/watch?v=2DDL47FRwRY

Real situation complex, non-linear:

We can simulate but not predict!

We can design systems that compensate for the effect in real time

http://www.youtube.com/watch?v=x3JkjXco6m0

http://www.youtube.com/watch?v=i5GIXJ-L-Cg&NR=1

Images from:

Lucky Exposures: Diffraction Limited Astronomical Imaging Through the Atmosphere;

PhD Thesis, University of Cambridge, Robert Nigel Tubbs

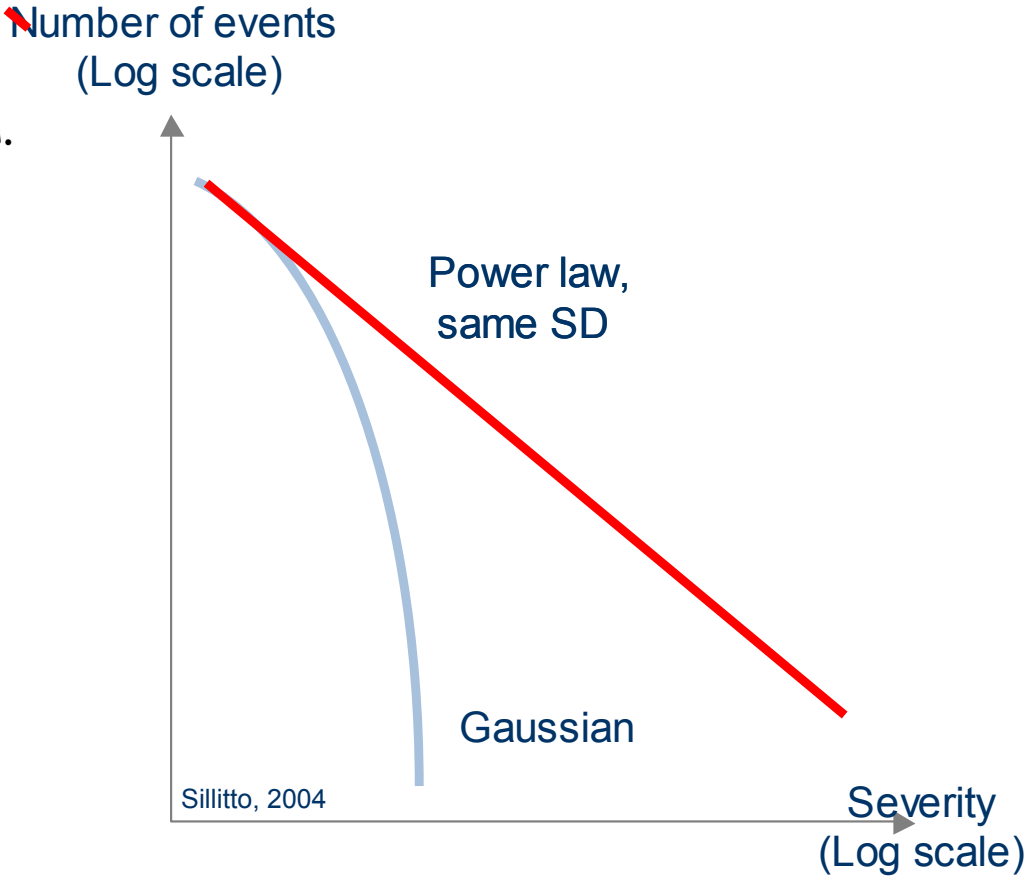
Power law: "signature of complexity"?

Sheard, 2005

There are two important things about the Power Law distribution.

It is found in a very wide variety of natural and man-made phenomena

It means that very large impact events are infrequent, but occur much more often than you might expect



Earthquake statistics and many other natural complex systems follow a power law (Malamud, 2004).

So do risks in projects (Allan, 2010)

Implications for risk mgt: (Jim Armstrong 2009)

INCOSE International Council on Systems Engineering

THALES

Organisations that specify, acquire, develop and operate the systems

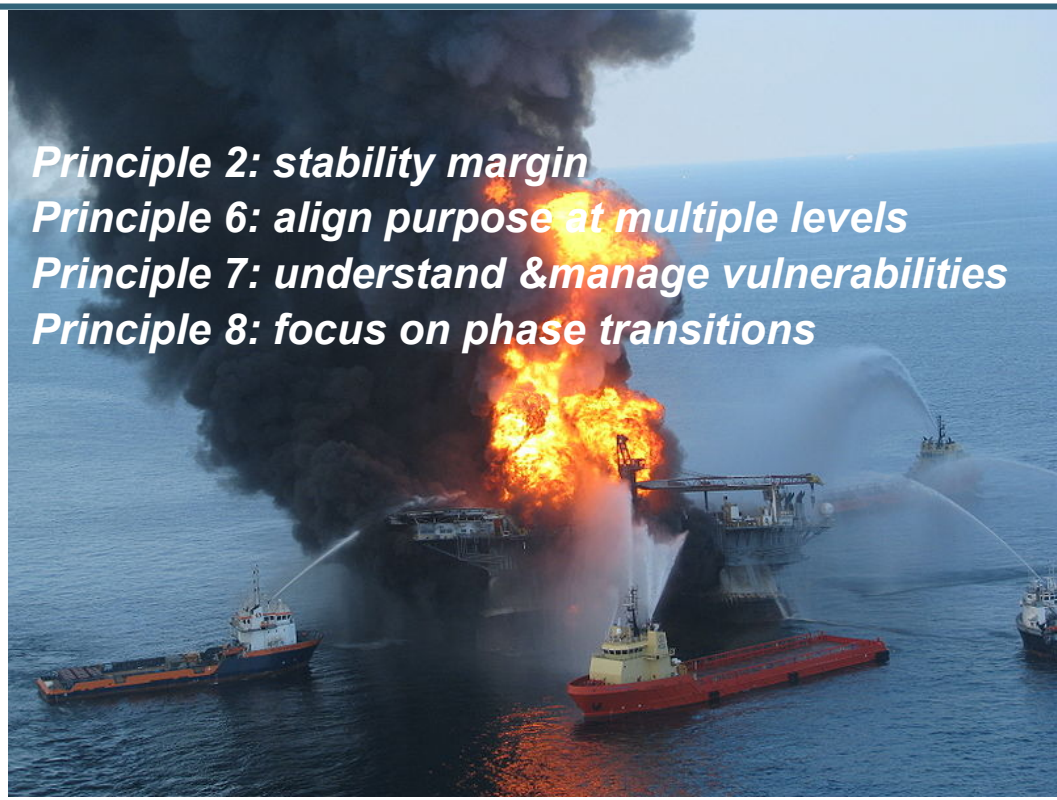
Procurement:

- select mainly on cost
- complex, unaligned supply chain
- no coherent system integration [Gray report]

Operation:

- drive for efficiency may erode stability margin and resilience culture

Low level problems - system wide consequences



Inter-element collaboration key to resilience (Jackson)

Free flow of information essential

- complex supply chains impede it; transactional/legalistic behaviour blocks it
- Alternative approaches have proved successful
- Heathrow Terminal 5 design and build – see [Blockley and Godfrey] for general approach
  - Problem at T5 was with principle 8 – focus on phase transitions [HCSC report]

INCOSE International Council on Systems Engineering

THALES

People

- part of the solution
- education and market signals align purpose at multiple levels (Principle 6)
- respond emotionally as well as (or instead of) rationally
- system design must consider emotional response

Nick Ut, Associated press, June 8 1972 – historic image from Wikipedia

John Bruno blog, http://www.climateshifts.org/?p=5423

Twin Towers attack, 9/11/2001: Wikipedia

Emergence

All systems have emergence

For ULSS it is their raison d'être

- they are composed to exploit the opportunities offered by large-scale emergence (Principle 3)

ULSS emergent properties must offer enough benefit to sponsors and critical stakeholders to offset

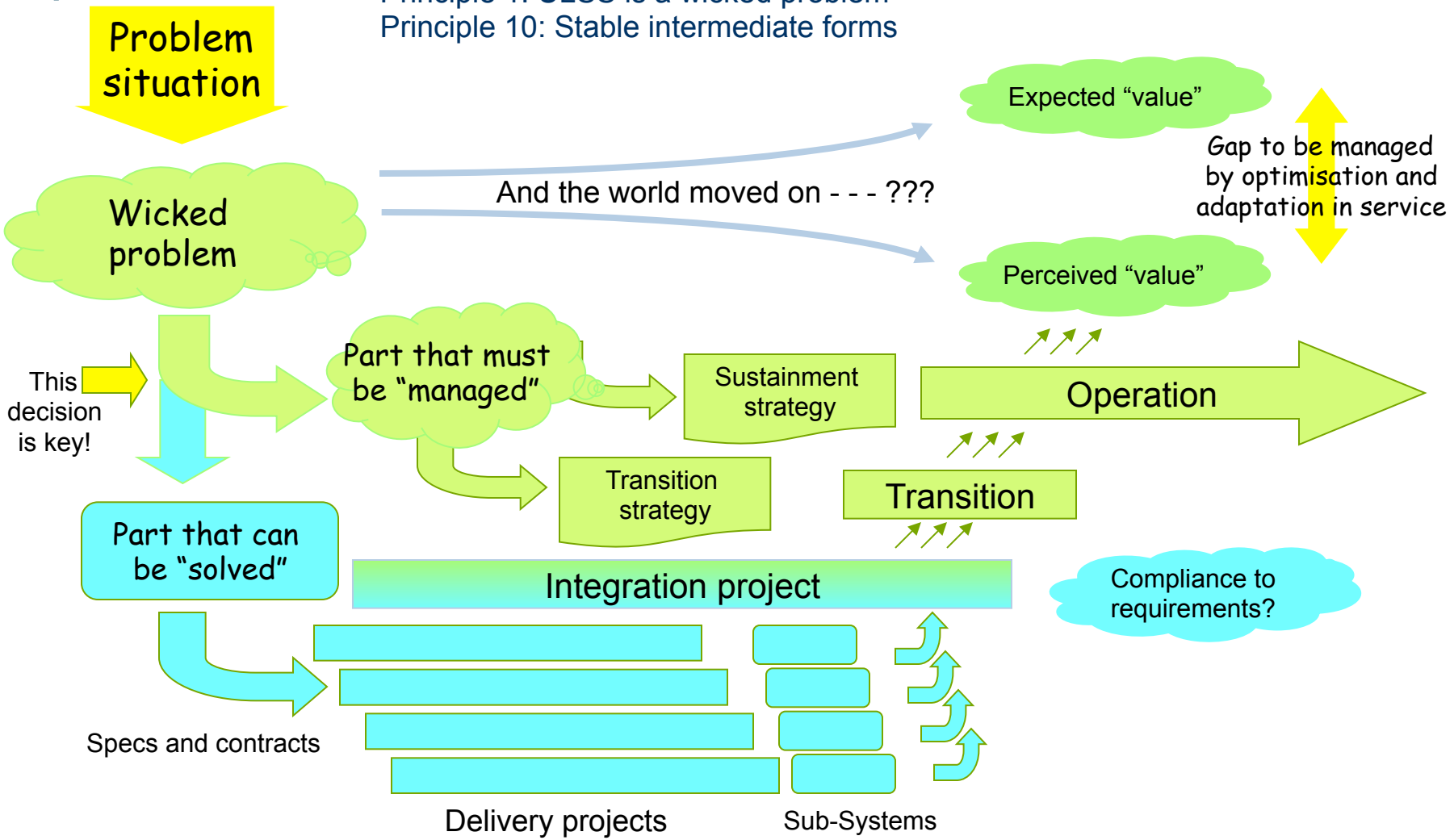
- additional costs of composing and governing the ULSS
- the risks created by the possibility of unintended emergence.

Engineering design domains that exploit emergence

- have good mathematical models of the domain,
- rigorously control variability of components and subsystems, and of process, in both design and operation

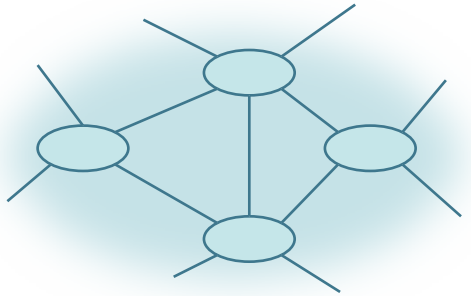
Constant reconfiguration and evolution

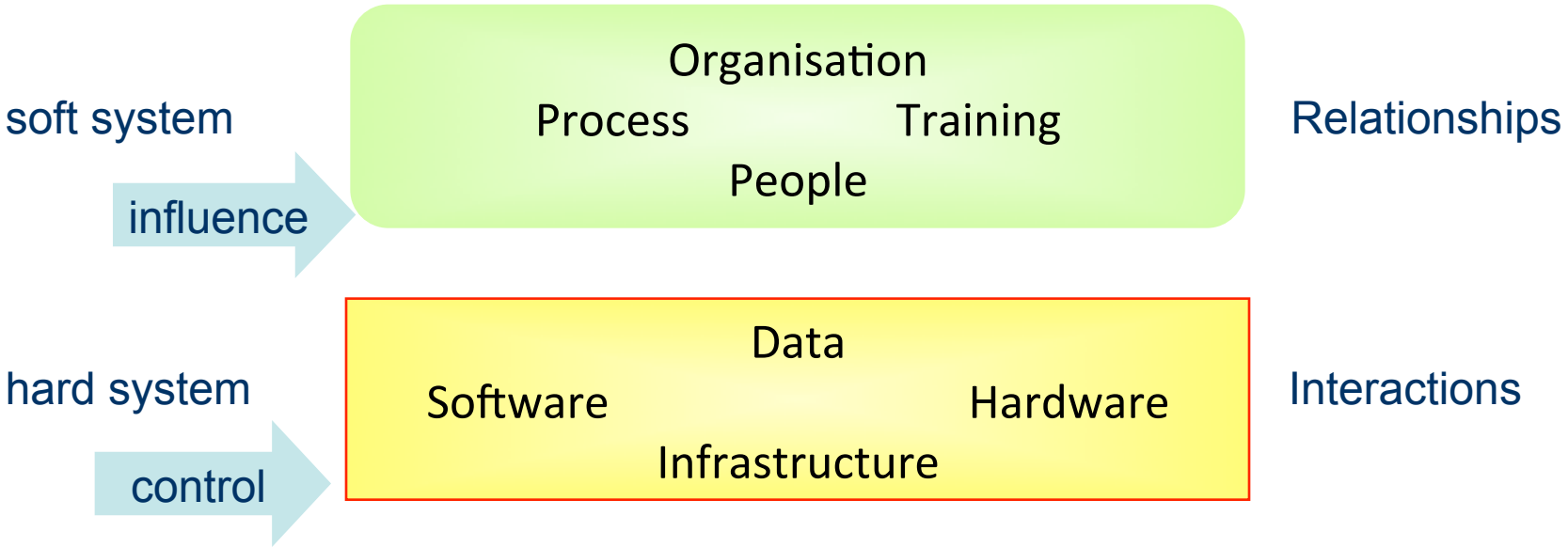
Principle 1: ULSS is a wicked problem
Principle 10: Stable intermediate forms



Physical architecture

- Nodes and their composition: organisation of resources
- Performance management
- Culture and motivation
- Interoperable in all layers





Understand available control levers

Practice 3

The right measures and mechanisms will depend on time constants

- how quickly information and effects propagate through the system
- how quickly decisions are made;

and on the gain

- the effect produced by each action.

If decisions are based on stale information and produce delayed effects,

- there will be delays and overshoots in response,
- the system may become unstable,
- the effect of actions will not be what was intended,
- the desired emergent properties will not be achieved.

Influence local self-interested decisions to create broadly aligned and synergistic collective behaviour

Effective and appropriate measurement

Practice 5

Why?

- optimise performance
- maintain stability
- optimise value

What happens at present?

- Contracts default to measuring what can be measured:
- performance, not value nor stability

What should we measure and lock into contracts to drive

- performance (to achieve outputs and system stability) ?
- behaviours (to create potential for added value)?

What else should we measure

- to detect unintended consequences?
- to optimise value?

How to incentivise inter-element collaboration?

Uncertainty is inevitable: must be accepted and recognized.

INCOSE International Council on Systems Engineering

THALES

Recap

5 key issues

- Complexity
- Emergence
- People in the system
- Constant reconfiguration and evolution
- Organisations that develop, buy and use the systems

10 principles

- ULSS is a wicked problem
- Stability margin
- Value adding, opportunity seeking
- Node and web architecture
- Layered architecture
- Align to common purpose at multiple levels
- Understand & manage vulnerabilities
- Focus on phase transitions
- Provide feedback relevant to decision cycles and available choices
- Stable intermediate forms

5 practices

- Physical architecture:
- Functional architecture:
- Synchronise effects with control levers
- Analysis and responsibility boundaries
- Effective and appropriate measurement

Analogies in other domains

Town planning; Economics; Military; Physics; Chaos and complexity theory

INCOSE International Council on Systems Engineering

THALES

In summary

"Complex systems evolve to the edge of chaos"

- understand, manage and protect "Stability margin"

Current systems already show ULSS issues and pathologies

- proper use of "best knowledge" will address many ULSS issues.

Gap between Architecture Frameworks and Model Driven Architecture.

- neither covers policies, values, behaviours and cultures, and emergence
- nor does anything else in current SE

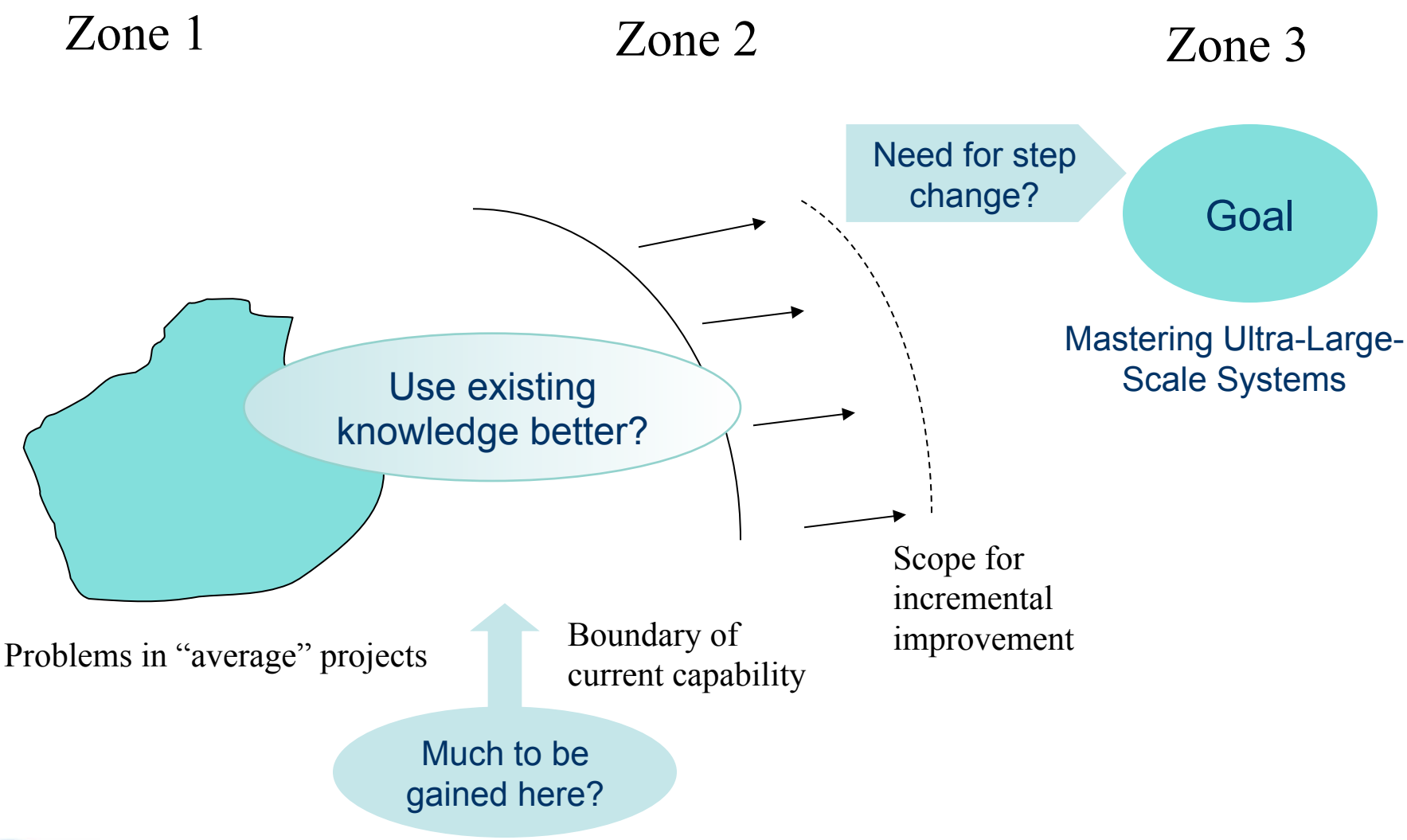
Two key architectural decisions for certification and evolution.:

- granularity of the system "chunks"
- behaviour centrally/locally defined and controlled

THALES

Thank you for your attention.
Any questions?

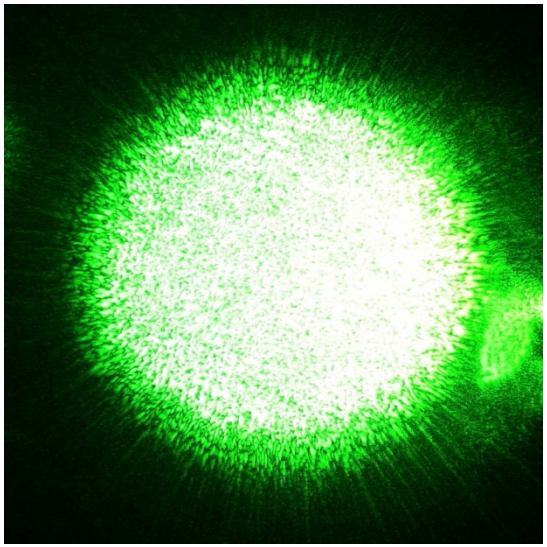
Do we need to go beyond state of the art or just apply it?



Complexity in Optics: speckle

Intensity = f(amplitude, phase)

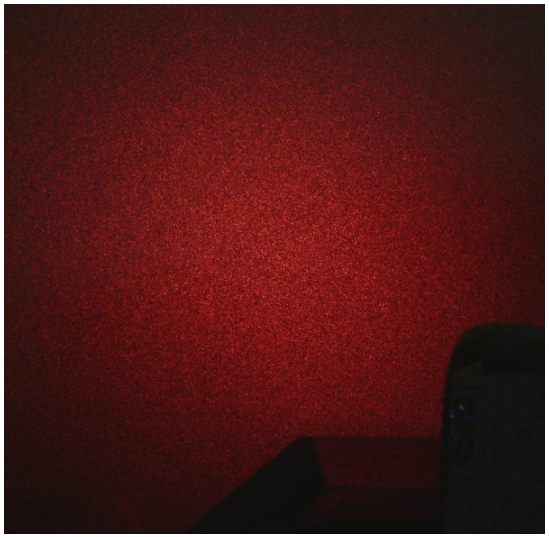
"Subjective" Laser speckle:



Laser speckle on a digital camera image from a green laser pointer.

Speckle is "in the eye of the beholder"

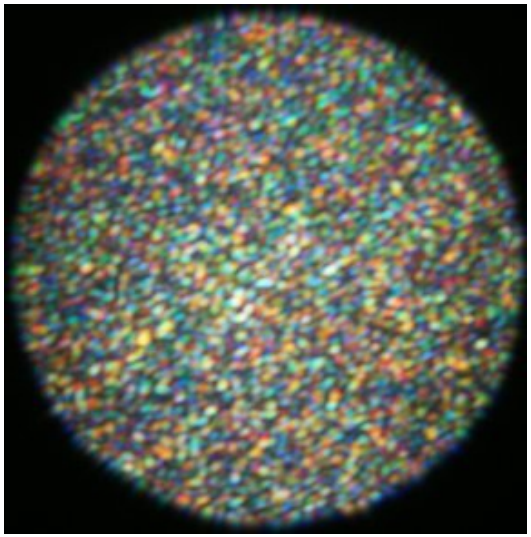
"Objective" Laser speckle:



Light field formed when a laser beam was scattered from a plastic surface onto a wall.

Speckle is independent of viewing conditions

Sun speckle on finger nail

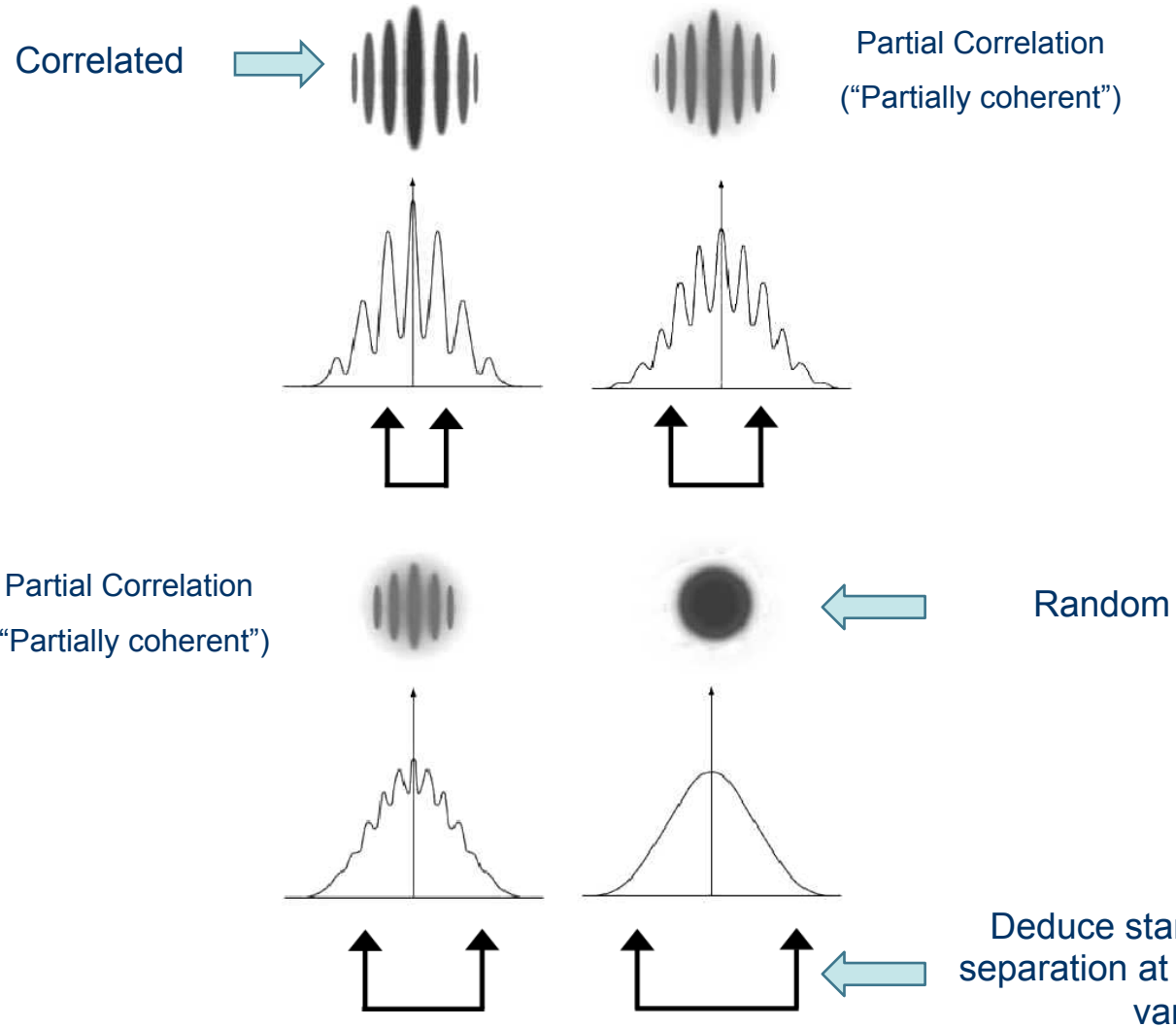


A sunlight speckle pattern photographed by Stewart McKechnie

http://www.sciencenewsforkids.org/pages/puzzlezone/muse/muse0705.asp

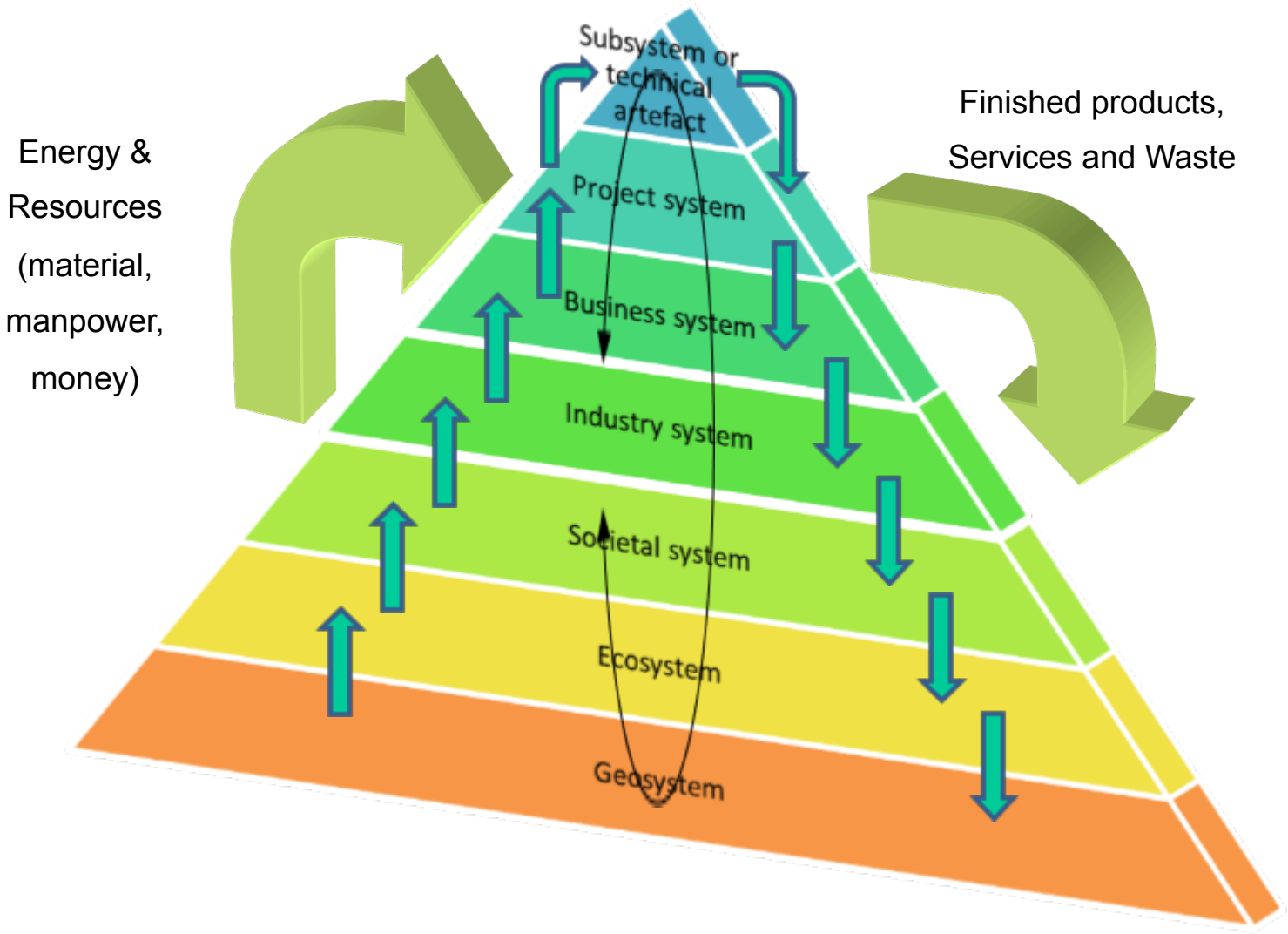
http://en.wikipedia.org/wiki/Speckle_pattern

Measuring distant stars from “partial coherence”



Images from internet: source TBC

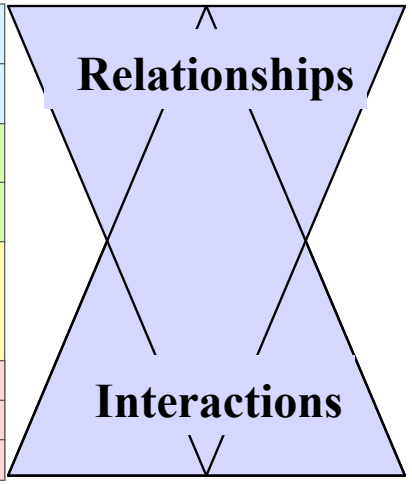
Expand our worldview to understand societal and environmental impact of technical problems



Making interoperability possible: layered architecture

Principle 5: Layered architecture

Social	Create shared mental models to change and align values, behaviours and actions across the enterprise	People	People	Personnel
		Organisation	Organisation	Organisation
Practice	End to end enterprise practices delivering political, strategic a nd operational effect	Process	Doctrine	Doctrine
			Training	Leadership
Information	The right information available to the right people at the right time- understood and trusted		Information	
Technical	Compatible, available, evolvable and reconfigurable assets to support the enterprise	Technology	Equipment	Technology
			Infrastructure	Facilities
			Logistics	Materiel
		POPT	TEPIDOIL	DOTMLPF



Key to scaleability

In a distributed complex system we want all nodes to conform to the layering principles. How to do this with heterogeneous "brown field" systems of systems?

DOTMLPF: Doctrine, Organization, Technology, Material, Leadership, Personnel, Facilities (US DoD)
TEPIDOIL: Training, Equipment, People, Information, Doctrine, Organisation (UK MOD)
POPT: People Organisation Process Technology (Garstka)

INCOSE International Council on Systems Engineering

THALES