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Complex Systems Engineering … What's the Difference?

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Rationale (Why am I here?)

- Symposium theme is …

  'Understanding Adaptivity to Deal with Complexity'

- One aim is to …

  'Place particular emphasis on the conceptual tools needed …'

Scope (What will I cover?)

- Challenges in engineering CAS
- Why Traditional Systems Engineering (TSE) might struggle
- Beyond TSE to Complex SE (CSE)
- TSE and CSE
- An alternative to CSE
- Conclusions

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Challenges in CAS Engineering

What makes CAS more difficult to engineer than (merely) complex systems?

Key Issue

- Systems not just getting bigger and more complex in a linear sense …
- … but ICT is allowing and encouraging systems to be ‘integrated’ and made ‘interoperable’ …
- … resulting in systems which resemble living ecosystems in some ways …
- … CAS and Systems-of-Systems (SoS)

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Why TSE Might Struggle with CAS / SoS

What makes CAS / SoS difficult for TSE to deal with?

What is TSE?

- Interdisciplinary approach and means to enable realization of successful systems.
- Focuses on defining customer needs and required functionality …
- Integrates all the disciplines and specialty groups into a team …
- Considers both the business and the technical needs …

(International Council on Systems Engineering (INCOSE) 2006 – abridged)

Why Does TSE Exist?

- Response to rapid increase in the complexity of military and aerospace projects in the decades after WW II
- Proven history of identifying end-user needs and translating into solutions

TSE Assumptions

- *A priori* knowledge of desired outcomes
- Single common manager
- Central introduction and management of change
- Resources can be applied and reallocated as needed

(Norman & Kuras 2004, p. 9)

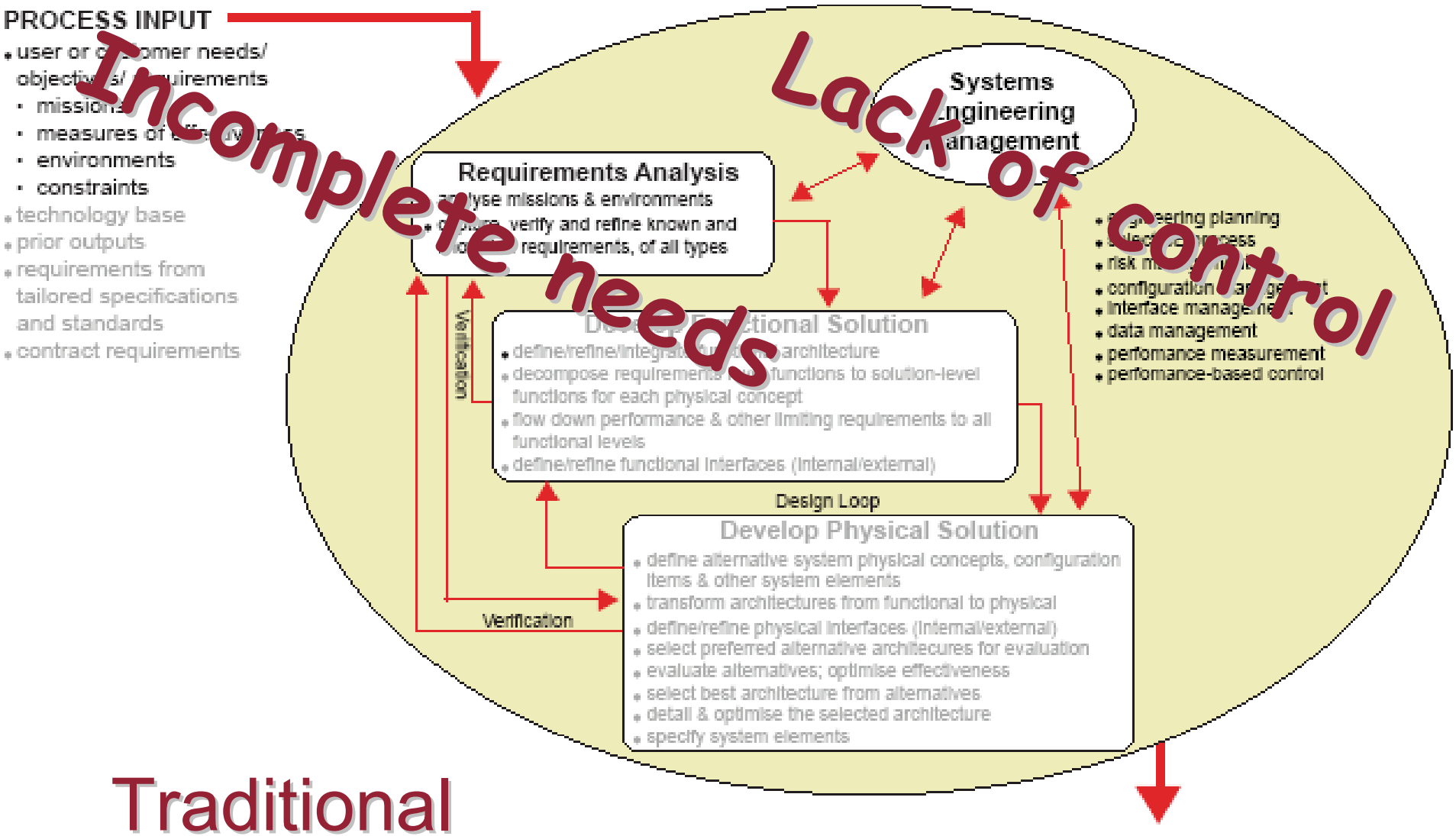
Challenges for Net-Centric Force Development

- 'Destination' is unclear or, at least, only defined at an 'outline' level of detail
  - What must the force be able to **do** (better)?
  - This is a different question from what is must (will) **be** (ORBAT etc)!
- ADF is a system-of-systems
  - Not just a scaled-up 'mega system'
  - Differences related to purpose & control

Defence Organisations as SoS

- Do not share a common conceptual basis
- Not built for the same purpose or for use exclusively within the 'parent' SoS
- Share an acquisition environment which encourages them to be standalone
- Have little or no **effective** common control or management
- No shared funding which can be directed to fixing integration 'problems' as required
- Many 'customers' of which the SoS capability is but one
- Evolve rapidly (particularly ICT) and at different rates subject to different, generally uncoordinated, pressures and needs

(Norman & Kuras 2004, p. 4)



Traditional Systems Engineering

PROCESS OUTPUT

- specifications & baselines
- decision data base
  - system functional & physical architecture and detail descriptions
  - decision support data
  - decision rationale data
- prototypes, where applicable

(Adapted from Technology Australasia Pty Ltd 1998)

Example of Lack of Control: *Defence Capability Development*

- Defence capability development (in Australia at least) is highly project-centric
  - Defence Capability Program (DCP) is, in essence, a collection of projects
  - Resourcing at project level
  - Management at project level (c'tees, etc)
- Result is that the ADF 'SoS' is built by numerous partially-autonomous agents

Example of Incomplete Needs: *HNA (Army devt) Desired Outcomes*

- Make best use of DCP
  - Negative political outcome if not achieved
- Enhanced survivability
  - Improved SA
  - Blue force ID → reduced fratricide risk
  - Enhanced targeting & lethality
- Improved sustainability
  - Networked logistics information systems
  - Just-in-time supply
  - Anticipatory 'push' supply
- Network-enabled *(this is an enabler itself!)*
  - Effectiveness (defined how?)
  - Survivability
  - Adaptability
- Better interoperability
  - Joint → via JCSS?
  - Coalition → via what?
- Increased capability & versatility
  - Rapid task transition (agility) (3-block war on same block)

(CA Directive 14/05 – *Hardened and Networked Army* as cited in Australian Army 2006, p. 1)

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Beyond TSE to CSE

Evolving engineering practice to suit CAS / SoS

Different Approach Needed

'... here is the solution designed from the requirements, now go implement it …'

to

'…here are the selective pressures acting on the elements present …, now resolve or reduce them …'

(Norman & Kuras 2004, p. 17)

History and Basis

- Defined by Norman & Kuras of MITRE Corp.
- From work on USAF Air & Space Ops Centres
- Applies at the 'enterprise' (SoS) level
- *'… deliberate & accelerated mimicry of the processes that drive emergence and natural evolution.'*
- *'… address[es] overall coherence without a direct and immediate attention to detail.'*
  - *Opposite to current Aust Defence process of (too much) detail (too) early in project development*

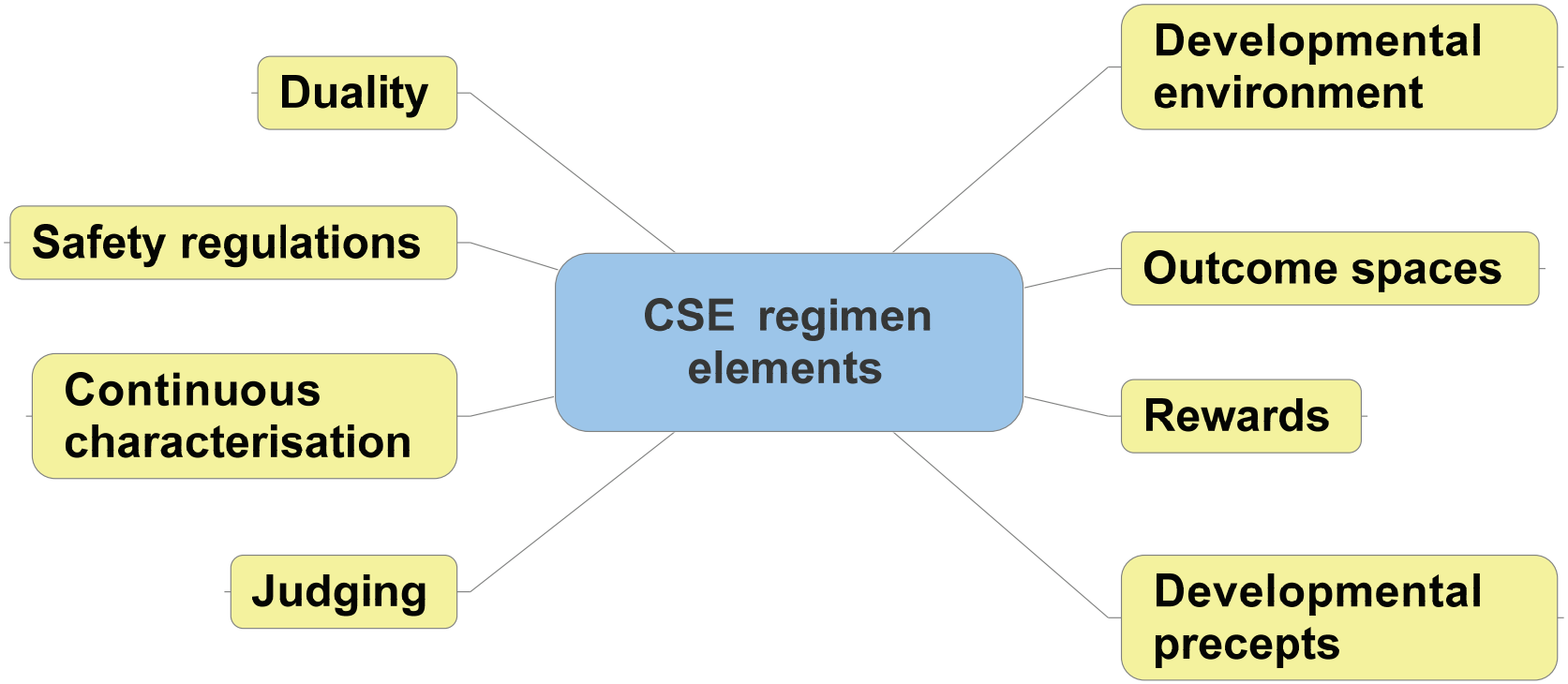
(Norman & Kuras 2004, p. 17)

Role of Autonomous Agents

- *"… acknowledges the presence and action of 'autonomous agents' as important elements of a SoS."*
  - Individual acquisition projects
  - Other parts of Defence community
- *'… creates and manages an environment in which multiple autonomous agents each address a fraction of the relationships that might be involved in an overall complex system.'*

(Norman & Kuras 2004, pp. 17 & 19)

CSE Regimen Elements



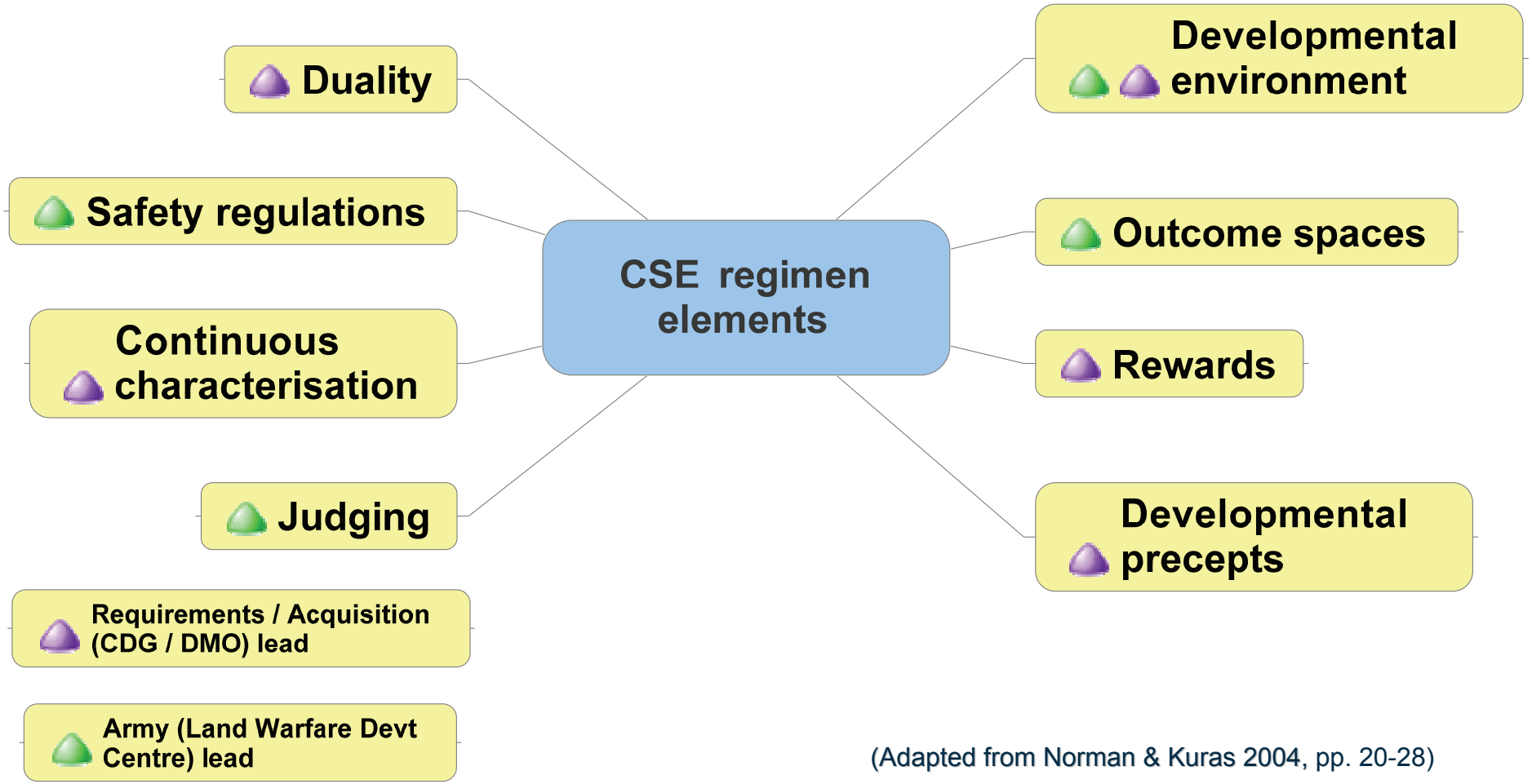
(Adapted from Norman & Kuras 2004, pp. 20-28)

CSE Elements Examples

Element	Defence example(s)
Developmental environment	Reqts & acquisition environments, military experimentation … but recognised and managed as a developmental environment
Outcomes spaces	Statements of intent in *Hardened & Networked Army* directive
Rewards	Access to financial resources for a project or passage through a development 'gate'
Developmental precepts	'Rules' – Australian two-pass-to-Government approval process
Judging	Still looking … Could be applied in spiral development?
Continuous characterisation	NCW assessment work done in Army 2003-2006
Safety regulations	Maintaining operational capability during change Stopping unsuitable capabilities being fielded
Duality	Relationships between operational and developmental environments through personnel exchange, feedback of experimental results, etc

(Wilson *et al* 2006, Section 9)

CSE Elements Allocated



(Adapted from Norman & Kuras 2004, pp. 20-28)

Running the CSE Regimen

- **Continuous formulation of desirable outcome spaces (not specific outcome points)**
- Creation of rewards available to autonomous agents expressed in terms visible to the agents even if the outcomes spaces themselves are not
- **Judging** and rewarding **of achievement of desirable outcomes**
- Binding developmental precepts that serve to influence (but not to specify) the decision-making of the autonomous agents
- Continuous characterisation emphasising those aspects that are associated with the state) of the system as it enters targeted outcomes spaces

(Adapted from Norman & Kuras 2004, p. 29)

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TSE and CSE

What's the relationship?

TSE versus CSE

TSE	CSE
Reproducible products	No two enterprises alike
Pre-conceived specifications	Continual evolution
Well-defined boundaries	Ambiguous boundaries
Unwanted possibilities removed	New possibilities assessed during enterprise evolution
Externally-driven integration	Self-integrating & re-integrating
Defined development endpoint	Never-ending development
Development ends when unwanted possibilities & friction removed	Enterprises depend on internal cooperation and competition to stimulate evolution

(Norman & Kuras 2004, p. 18)

TSE within CSE

- CSE is not an abandonment of TSE

- TSE and CSE should be …

  '… applied concurrently in the realisation and evolution of a complex system. TSE is appropriate for managing the decision-making processes of individual autonomous agents in a complex system. CSE must be added when multiple autonomous agents must be part of any solution …'

(Norman & Kuras 2004, p. 18)

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An alternative to CSE

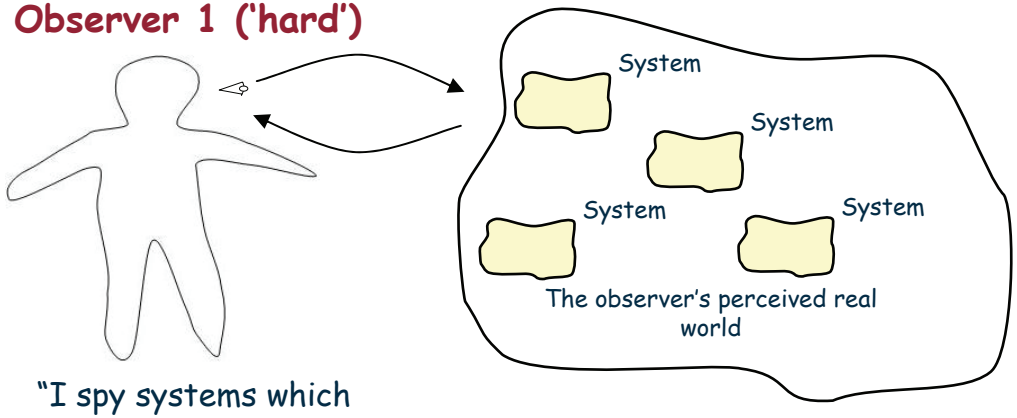
Checkland's Soft Systems Methodology (SSM)

History and Basis

- Developed in 1960s/70s to deal with large-scale ‘problematic situations’
  - Socio-technical systems
  - British National Health Service (NHS)
- Focuses on situation modelling
  - Describe system elements as-is
  - Describe in terms of functions to be performed or contribute to
- Seeks actions to improve the situation

‘Hard’ versus ‘Soft’

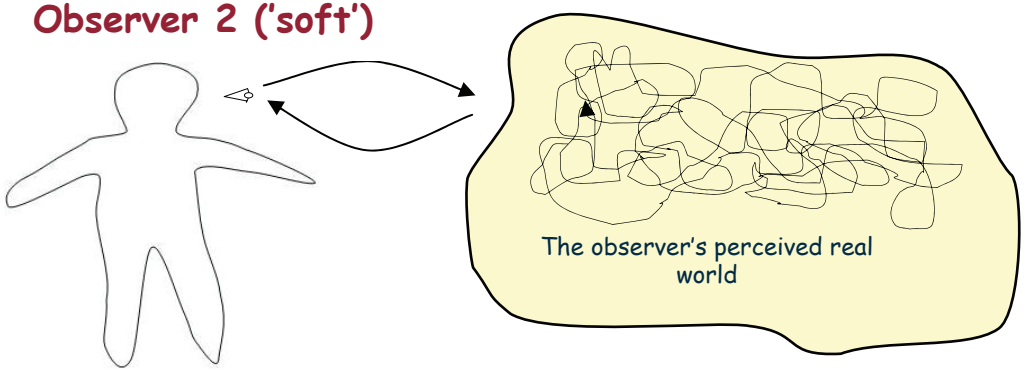
Observer 1 (‘hard’)



“I spy systems which I can engineer”

The World: Systemic

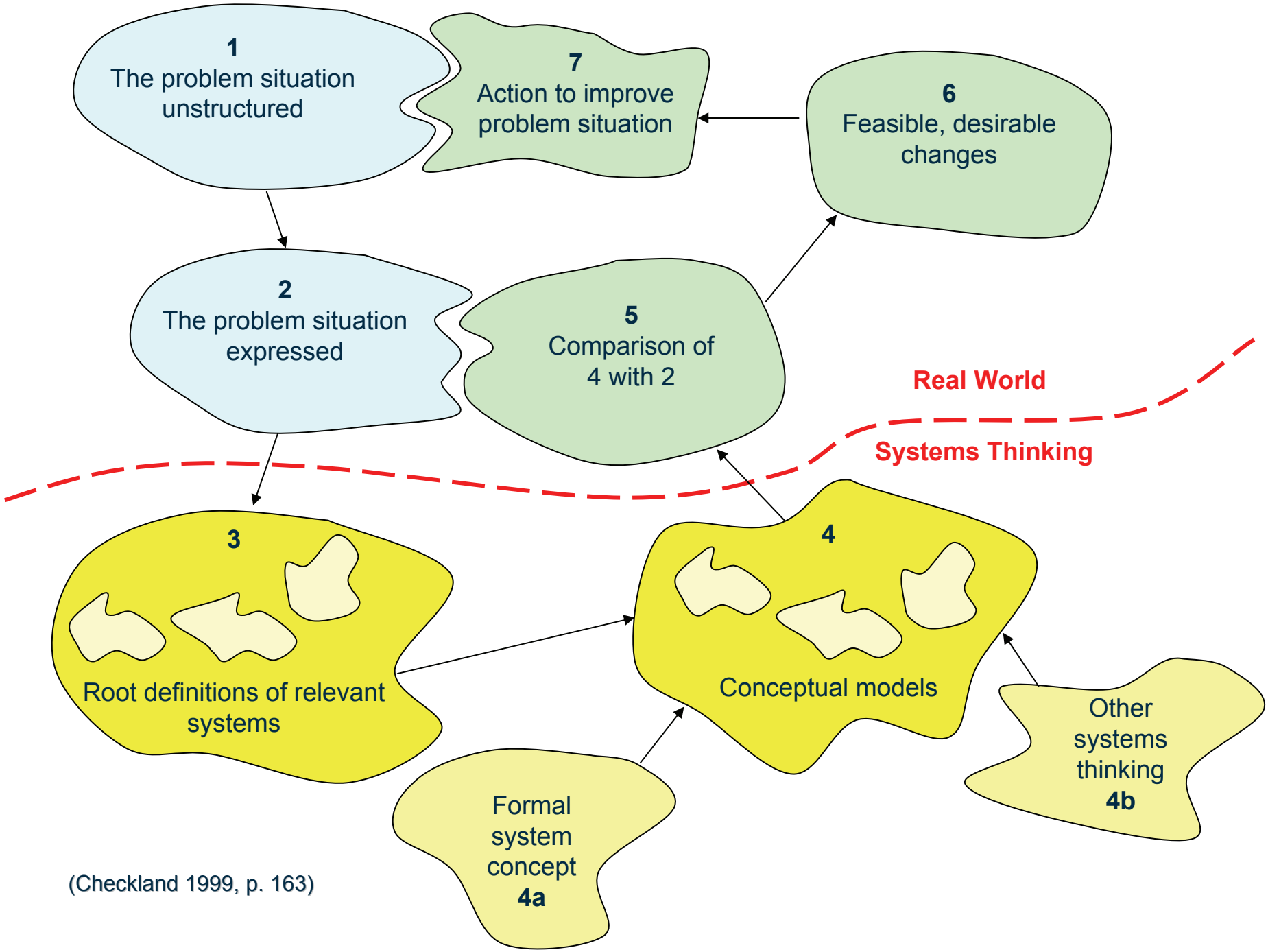
Observer 2 (‘soft’)



“I spy complexity and confusion; but I can organise exploration of it as a learning system”

The Process of Enquiry: Systemic

(Checkland 1999, p. A11)



(Checkland 1999, p. 163)

SSM and CSE

- Recognition of impracticality of pre-specification
- Role is influence on autonomous agents, not central control
- The developmental environment is as important as the outcome environment
- *We are currently working to synthesise an approach based on the relevant aspects of SSM and CSE (and others)*

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Conclusions

What does CSE mean to us in Defence?

What does it all mean?

- TSE is, arguably, deficient for CAS / SoS engineering challenges (the debate is only just beginning)
- Defence presents lots of such challenges
- CSE offers a promising way forward based on (apparently) mimicking natural processes
- But not the only approach
- … we (the SE community) have lots of work to do to create a 'mature' approach to engineering of CAS / SoS

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Questions, please …

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