Australian Government
Department of Defence
Defence Science and
Technology Organisation

Implications of Complex Adaptive Systems Theory for C2

20 June 2006

Dr Anne-Marie Grisogono

Land Operations Division
Defence Science and Technology Organisation

In a Nutshell . . .

- What are complexity and adaptivity?
- What we have learned so far from studying adaptation
  - *Conceptual Framework for Adaptation*
- Essential character of C2
- Putting it all together …
  - *Complexity and CAS in defence*
  - *Control, Influencability and Predictability*
  - *C2 as an adaptive mechanism*
  - *Opportunities for increasing adaptivity in defence*
  - *Understanding of CAS to deal with opponents and allies*
  - *Foster desirable adaptivity properties in our own force*
  - *The importance of understanding success and failure*
- Concluding Remarks

What are Complexity and Adaptivity?

Symptoms of Complexity:

- simple cause –effect models fail
- impossible to optimise
- 'rules' seem to keep changing
- unintended consequences,
- see coherent behaviour but we are uncertain about
  - *outcomes of actions and*
  - *which actions are most likely to produce desired outcomes*
- → big problems if we need to command, manage or design the system or situation
  - *traditional approaches of command, management, & systems engineering break down*

Biologically inspired

Adaptivity:

- is different from reactive behaviour
- presupposes a concept of 'better' or 'success'

Exhibited by natural CAS.

Is this a possible solution to our complexity problems?

Can we learn from natural CAS?

Increasing Complexity requires Adaptivity

Things are getting tougher for defence – we face increasing...:

- diversity of defence roles & security challenges ... ➔ more to deal with
- uncertainty and pace of change ... ... ➔ less time to adapt
- complexity and inter-relatedness ... ... ➔ less predictable
- constraints and public scrutiny ... . ➔ less options

All this ➔ defence cant be sure, in advance, of:

- what it will have to do, and who with, ... so cant optimise
- when it will have to do it, ... so cant prepare
- how to ensure successful outcomes, ... so cant control

dynamic properties of the force that 'emerge' as a result of many decisions about structure, process, doctrine, personnel, equipt, training, ...

Therefore the premium will be more on the ability to ...

- rapidly decide, *as situations develop,* what is to be done, how, who with, & how to measure success
- rapidly assemble tailored diverse (incl non-defence elements) teams and get them operational and effective,
- maintain effectiveness under unpredictable and rapidly evolving conditions, retaining ability to mount additional ops as needed

... requires Adaptivity

... rather than on the ability to do particular kinds of operations very well – which is the 'usual' kind of mission effectiveness

What we have learned so far from studying CAS and adaptation

- **CAS are complex systems which are adaptive – i.e. structure and behaviour of the system changes over time in a way which tends to increase its 'success'.**
- **Being adaptive requires**
  - *i. concept of 'success or failure', or 'fitness', for system in its context*
  - *ii. a source of variation in some internal details of the system, and*
  - *iii. a selection process, i.e. the system preferentially retains/discards variations which enhance/decrease its fitness, which requires…*
  - *iv. way of evaluating impact of a variation on fitness – through feedback from external or internally modelled interaction.*
  - *v. Thus over time system generates and internalises variations which tend to increase its fitness or success – amounting to incorporation of information into the system.*

Australian Government
Department of Defence
Defence Science and Technology Organisation

What we have learned so far from studying CAS and adaptation

Many CAS properties come in complementary pairs with conflicting requirements, eg:

1. robustness to damage requires changes inhibited and repaired, ⟷ innovation requires some system changes amplified,
2. coherent behaviour requires some aspects stable and persistent, ⟷ context-appropriate behaviour requires aspects sensitive to influences to tip balance one way or other,
3. 'intelligent' behaviour in complex environment may require specialised system elements, ⟷ Flexibility, resilience put premium on multi-purpose system elements,
4. effectiveness needs competition bet. elements to refine individual strategies, ⟷ effectiveness needs cooperation between elements to produce collective strategies,
5. effectiveness in dealing with current environment requires conformity of system properties to those presently most relevant and effective. ⟷ effectiveness in dealing with a changing environment requires diversity of system properties.

dynamic processes control & balance such paired properties → grow our ability to work effectively with and within CAS.

Conceptual Framework for Adaptation

for details see paper and references

- **A generic model of adaptation** – *what it is*
- **Measures of success and failure** – *what steers it*
- **Types of adaptive mechanisms** – *implementation strategies*
- **Classes of adaptive mechanisms** – *what it deals with*
- **Levels of adaptation** – *what aspect of the system is adapting*
- **Scale of adaptive mechanisms** – *where it is applied*
- **Health of adaptive mechanisms and factors that influence its effectiveness** – *what it takes to make them work*

- **+** ***Framework for Addressing Complex Problems***
  CAS Diagnostic tools,
  analysis of temporal dynamics and
  adaptivity implementation guidelines

Australian Government
Department of Defence
Defence Science and Technology Organisation

4 Classes of Adaptivity

Robustness of force to the unknown future

Robust-ness of force to damage, & shocks during ops

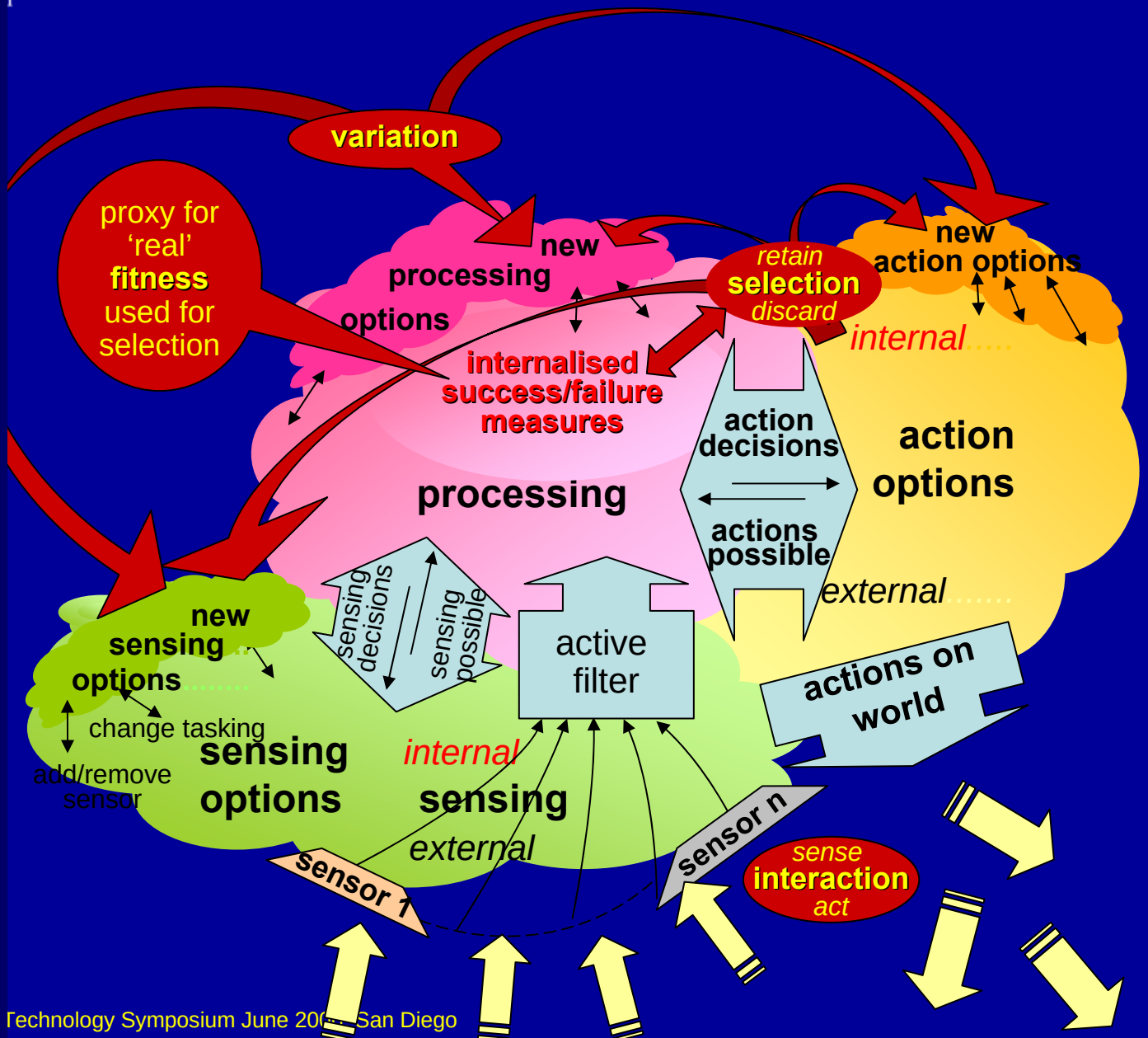
Robust-ness of force to the unexpected during ops.

Robust-ness of force to changing conditions during ops.

	Change to be dealt with			Response needed		Implications for C2	
	Time-scale	Effect-scale	int / ext	Time-scale	Effect-scale	to enable adaptivity	adaptivity of C2
Flexi-bility	Slow *time for new reqt to emerge*	major, wide-ranging	external	to match	major	how C2 enables flexibility	how to make C2 flexible
Resi-lience	Fast	from local up to major	internal	timely	all scales	how C2 enables resilience	how to make C2 resilient
Respon-siveness	Fast	local	external	im-mediate	local	how C2 enables respons-iveness	how to make C2 respons-ive
Agility	Inter-mediate	major, and/or wide	External and/or internal	rapid	Signifi-cantly different strategy	how C2 enables agility	how to make C2 agile

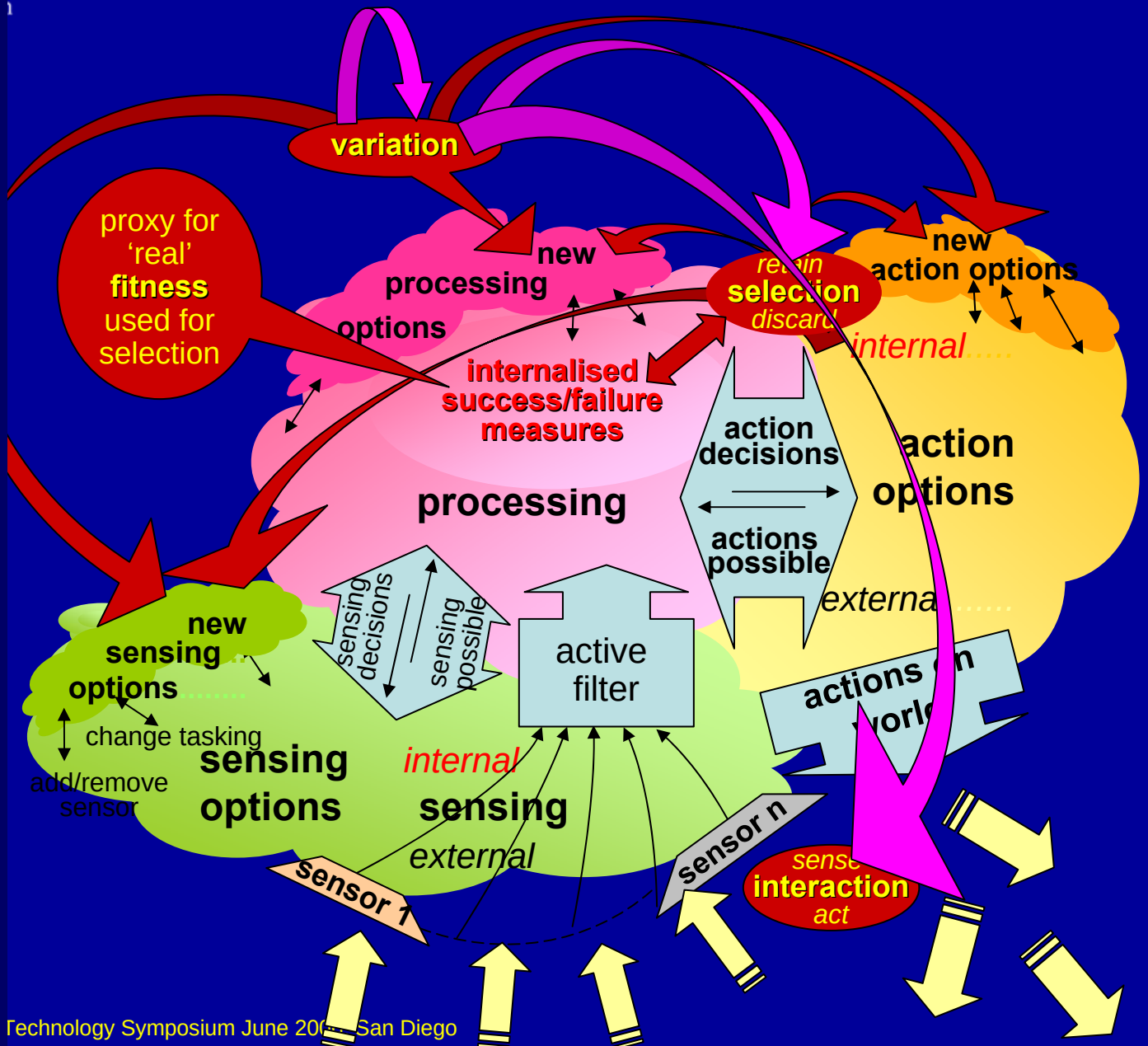
Five Levels of Adaptation

1. Action *Tunes the system*
2. **Learning** ***changes system***
3. Learning-to-learn *improves how system changes*
4. Defining Success *calibrates the compass*
5. Co-Adaptation *tunes how we use SoS*



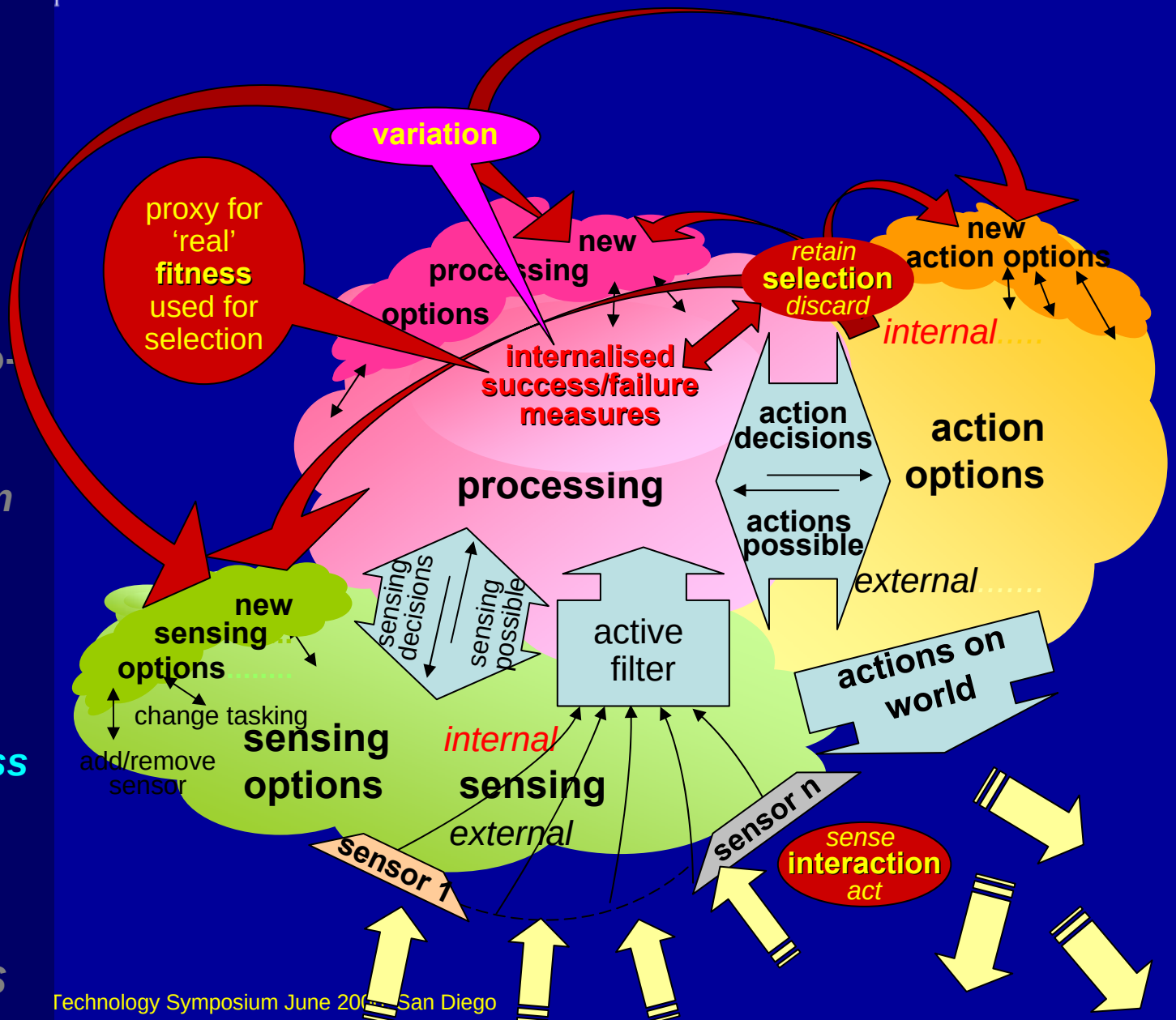
Five Levels of Adaptation

1. Action
   Tunes the system
2. Learning
   changes system
3. **Learning-to-learn**
   improves how system changes
4. Defining Success
   calibrates the compass
5. Co-Adaptation
   tunes how we use SoS



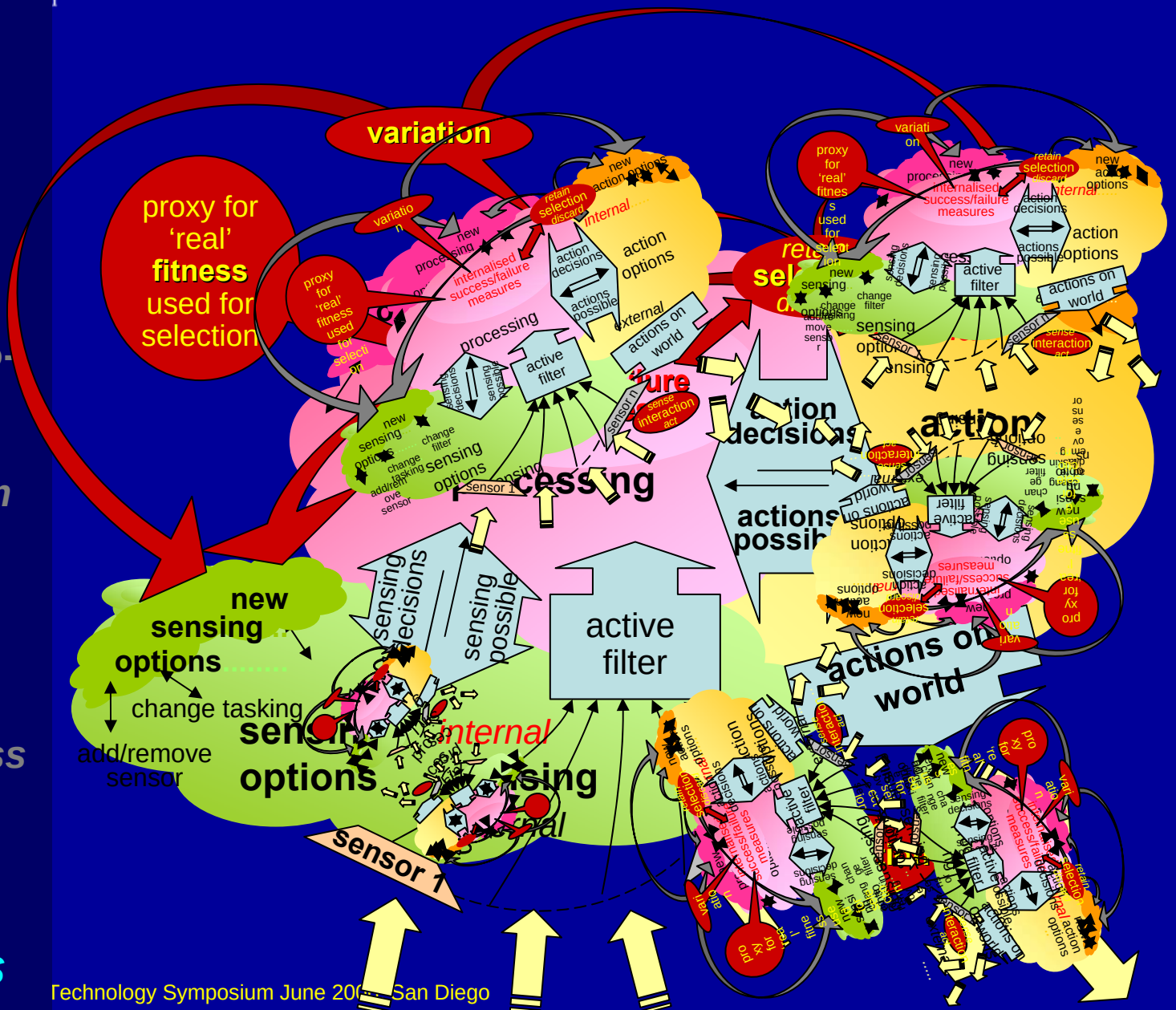
Five Levels of Adaptation

1. Action *Tunes the system*
2. Learning *changes system*
3. Learning-to-learn *improves how system changes*
4. **Defining Success *calibrates the compass***
5. Co-Adaptation *tunes how we use SoS*



Five Levels of Adaptation

1. Action *Tunes the system*
2. Learning *changes system*
3. Learning-to-learn *improves how system changes*
4. Defining Success *calibrates the compass*
5. **Co-Adaptation** ***tunes how we use SoS***



How the Conceptual Framework For Adaptation can be used

1. as a template for identifying the informal adaptive loops that arise spontaneously in any complex sociotechnical system, coexisting with, and often undermining the deliberate formal adaptive mechanisms;

2. for analysing the factors determining the effectiveness of both formal and informal adaptive mechanisms, and suggesting leverage points for modifying them; and

3. for designing new adaptive mechanisms to deal with anticipated future pressures and changes.

All these approaches → significant insights into

- *how defence systems should be architected, and*
- *how decisionmaking, C2 processes, information and policy should be organised and managed for the required degrees of robustness and adaptivity.*

Essential character of C2

C2 is about

- determining objectives, and
- under constraints,
- choosing and causing actions so as to increase probability of achieving those objectives.

through shifting perceptions and assessments in the cognitive domain

i.e. bring about outcomes which contribute to shaping the future that unfolds in the directions set by higher intent.

C2 Roles

1. understand higher intent in space of possible futures, & negotiate defence role in implementing that intent,
2. determine outcomes defence must produce / avoid to in that role, alone or in cooperation with other agencies
3. choose defence actions to undertake to produce / avoid those outcomes,
4. cause those actions to happen, and
5. monitor & continuously re-assess all above as events unfold.

Putting it all together … 1

Complexity and CAS in defence

Examples of CAS in defence:

- combat teams
- corps culture
- an adaptive command support system
- the capability development system
- defence industries
- logistic systems
- individual humans

our own systems

all socio-technical systems

- government and NGOs
- the media and public opinion
- adversaries/allies
- civil infrastructure

others' systems

What makes these systems complex is the network of elements and interactions.

What makes them adaptive are interacting and tuned +/- feedback loops.

These contain designed elements but are not designed as CAS – so they are not necessarily adapting towards desired 'fitness'

If we cant control CAS we would at least like to:

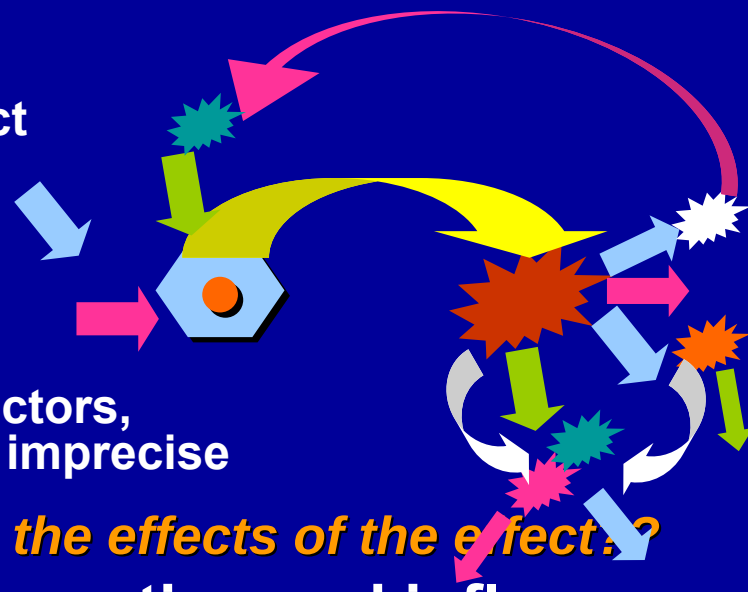
- **understand ...**
- **influence/shape ...**
- **be confident of their behaviour ...**
- **modify/improve ... and**
- **even design them!**

To do this we need to understand how adaptivity works and how it fails

Putting it all together … 2

Control, Influencability and Predictability

- **one cause – one effect**
  - *linear relationship:*
    - proportional response
    - → if can control cause, can control effect
    - additive causes → additive effects
  - *non-linear relationship - can be*
    - deterministic, stochastic, or hybrid
    - 'nice' or 'nasty'
    - if relationship depends on contingent factors, interventions → very difficult and imprecise

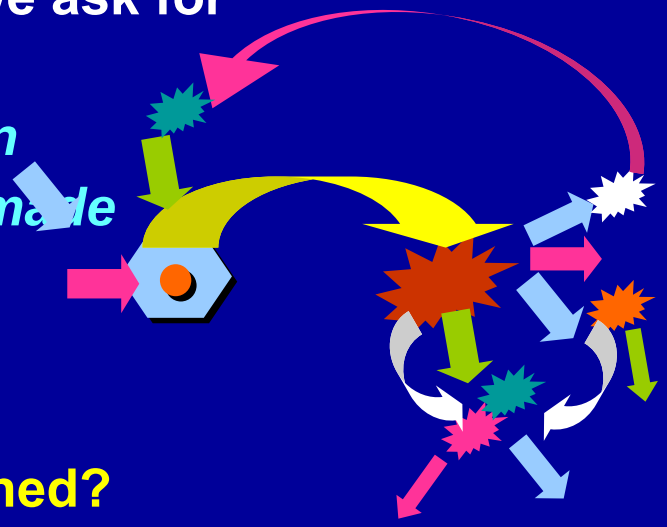


but what caused the cause? and what are the effects of the effect?

- **What we really have is networked causation and influence**
  - *multiple causal and influence relationships on any event*
  - *multiple cascading consequences of any event*
    - predictability may reduce rapidly, even if all relations are deterministic,
    - it doesnt take very many interacting influences to become intractable,
    - some parameters may not be accessible for measurement,
    - some relations may be extremely sensitive to exact values of params
    - → criticality, tipping points, phase changes, chaos, ... but also stabilities, attractors, coherence, ... the domain of complex systems

Putting it all together … 2
Control, Influencability and Predictability

- predictability is not a binary property - have to give up 100% predictability and control
- ... but we can still have influence and *some* predictability
- paradoxically emergent properties in CAS increase predictability!
- Degree of predictability depends on what we ask for
  - *precision of effect we require*
  - *selectivity of which effects we focus on*
  - *time horizon over which prediction is made*
  - *required confidence of prediction*
  - *direction of prediction in time*
    - forwards = what happens next?
    - backwards = what must have happened?
    - sideways = what else must be happening now?



random — complex — classical mechanics

0 — predictability — 100

Australian Government
Department of Defence
Defence Science and Technology Organisation

Putting it all together … 3

C2 as an adaptive mechanism

C2 Roles

1. understand higher intent in space of possible futures, & negotiate defence role in implementing that intent,
2. determine outcomes defence must produce / avoid to in that role, alone or in cooperation with other agencies
3. choose defence actions to undertake to produce / avoid those outcomes,
4. cause those actions to happen, and
5. monitor & continuously re-assess all above as

Determining measures of success and failure

for

Adaptive action

Examples

- Mission command
- MAP *(esp as actually performed…)*
- IPB
- Mainly at action level
- Some Level 2 learning…
- … but in conflict with need to standardise

Putting it all together … 4

Opportunities for increasing adaptivity

- Enhance level 1 and 2 adaptation for individuals and teams
- Enable, support and enhance human adaptivity through applying Dörner's insights *(ref in paper)*
- Apply adaptation to higher scales of defence organisations eg with insights from organisational science literature
- Apply Levels 3, 4, 5 … *see paper for details*
- Even Level 1 is not fully exploited – can design much more adaptive systems than we currently have

Putting it all together … 5

Use CAS to better deal with others

Middle ground where CAS and EBO offer options

CAS also shows how to get better at it

Decide where to operate on spectrum:

destroy ← - → seek to shape and influence ← - → accept and live with

Requires us to

1. **explore**
   - **what are its adaptive mechanisms?**
   - **What levels of adaptivity do they have?**
   - **what are its success and failure criteria?**
   - **what scales exist? How do they interact?**
   - **what info do they seek & have?**
   - **what response options do they have?**
   - **how do they process info and how do they decide?**
   - **how much variety/diversity do they allow?**
   - **what is their interaction structure?**
   - **how are new ideas generated and evaluated?**
   - **how are policies enforced?**
   - **What conflicts are there between its adaptive mechanisms and how could they be exploited? …**
2. **Over time, refine initially crude models of the others' systems…** *5 levels can help*
3. **Identify, test and refine intervention options** *(continuum from 'learning' probes to 'influence' options)* **… i.e. start lightly, gradually build confidence, effectiveness.**

Putting it all together … 6

Foster desirable adaptivity properties in own force

Clarify objectives:

- **What dynamic emergent properties are desired and what is their optimum level? How can they, or good proxies, be measured? Over what timescale?**

Debug adaptive mechanisms we already have:

- **What existing adaptive mechanisms affect the desired properties?**
- **Are they healthy and tuned to produce the desired outcomes?**
  - *are the loops continuous or broken?*
  - *does every element have the information, resources, authority and motivation it needs to perform its role?*
  - *is the selection process well-aligned with the desired outcome?*
  - *are there conflicts with other adaptive mechanisms?*
  - *are higher levels of adaptivity needed? and if so, are they employed?*

What additional adaptive mechanisms are needed?

- **identify the class, level and type of adaptive mechanisms required**
  - *identify the sense, decide and act elements needed*
  - *identify the linkages, authorities and incentives needed*
  - *identify the sources and targets of variation, interactions and selection processes to implement the higher levels of adaptation as needed...*

Putting it all together … 7

importance of understanding success and failure

- Internalised measures determine where you're going
- Comprehensive set of measures or else distortion sets in
- This is nexus between EBO and CAS theory
- 'espoused' values & intent ≠ how selection actually operates
- Need for proxies:
  - *shorter-term observable outcomes, not themselves the primary outcomes we care about, but correlate well with longer-term 'real' success and failure measures and can be detected fast enough to allow adaptive action in response*
- and indicators:
  - *observable outcomes that give indication of what path unfolding chains of interrelated events and influences are taking and in particular, whether on path to success (so stay with current CoA and keep monitoring) or veering to failure (so corrective action needed)*
- Use retrospective hindsight measures to support level 4

Concluding Remarks

- CAS at many levels in defence: humans, groups, organisations, socio-technical systems – our own and those of others.
- CAS science offers useful new options to deal better with CAS.
- The implications for defence are significant:
  - ***Understand limits of traditional approaches***
  - ***Develop new adaptation-based approaches – builds on existing capabilities to deal with people, to plan, to be adaptive, but goes further***
  - ***Understand how to get better at being adaptive***
  - ***Understand how to 'grow' complex systems rather than engineer complicated ones***
  - ***Embracing adaptivity generates consequences for all the lines of development and for networking – this is the concept that should lead NCW***
  - ***Can select, train and educate people to be adaptive***
  - ***Can design systems to be much more adaptive than at present***
  - ***Rethink C2, ISR, NCW, EBO, …***
  - ***Understand and intelligently manage the many System-of-system tradeoffs***

And now a word from our sponsors…

Defence Science and Technology Organisation
and the
TTCP Joint Systems and Analysis Group
Present

pan-TTCP Symposium on Complex Adaptive Systems for Defence

Theme: Understanding Adaptivity to Deal with Complexity

http://www.dsto.defence.gov.au/events/4197/

Stamford Grand Hotel,
Glenelg, Adelaide, South Australia
July 16-21 2006

Questions?