Graphical Representation of Situation Awareness in Joint Cognitive Systems

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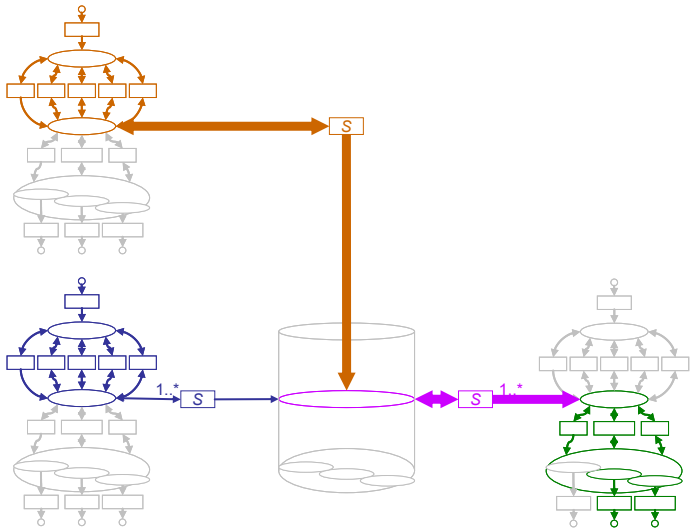
Central idea

- Charting of joint cognitive systems (humans & machines) to examine:
  - Where is situation awareness being held (or lost)?
  - How is situation awareness used in the system's workflows?
  - How can we make improvements (via design, technology)?



Overview

- Situation awareness (SA) as a focus of systems engineering
- Graphical representation of
  - SA in an individual agent
  - SA across multiple agents
  - Architectures for joint cognitive systems
- Case Study - Field artillery with digital technologies

Why is situation awareness topical?

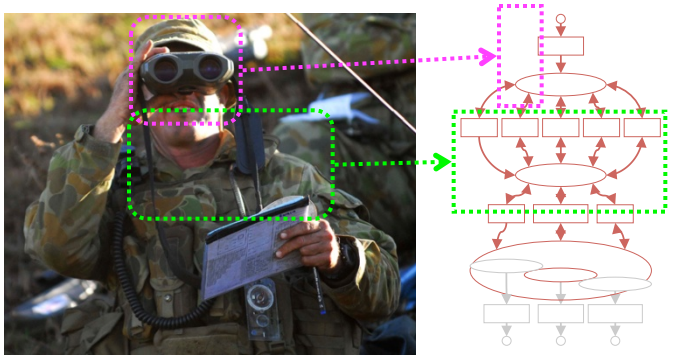
- SA is fundamental to effective human functioning in complex systems (Endsley et al, 2007)
- "Enhanced situational awareness leads to better decision-making" (Australian Defence Force Network Centric Warfare Roadmap, 2009)

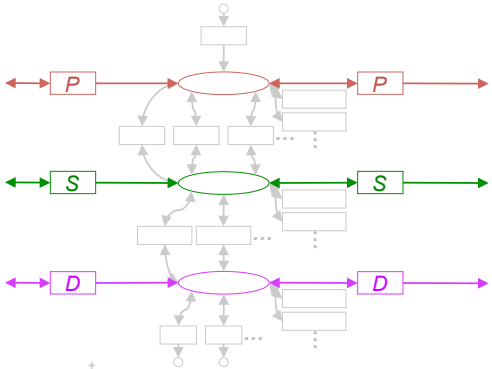
- *but*
  - Systems engineers lack methods for studying SA in joint cognitive systems (humans & machines)
    - Extant methods are for engineering the human-machine interface to individual people

Mica R Endsley, Robert Hoffman, David Kaber, and Emilie Roth. 2007. Cognitive Engineering and Decision Making: An Overview and Future Course. *Journal of Cognitive Engineering and Decision Making* 1 (1):1-21.

Approach

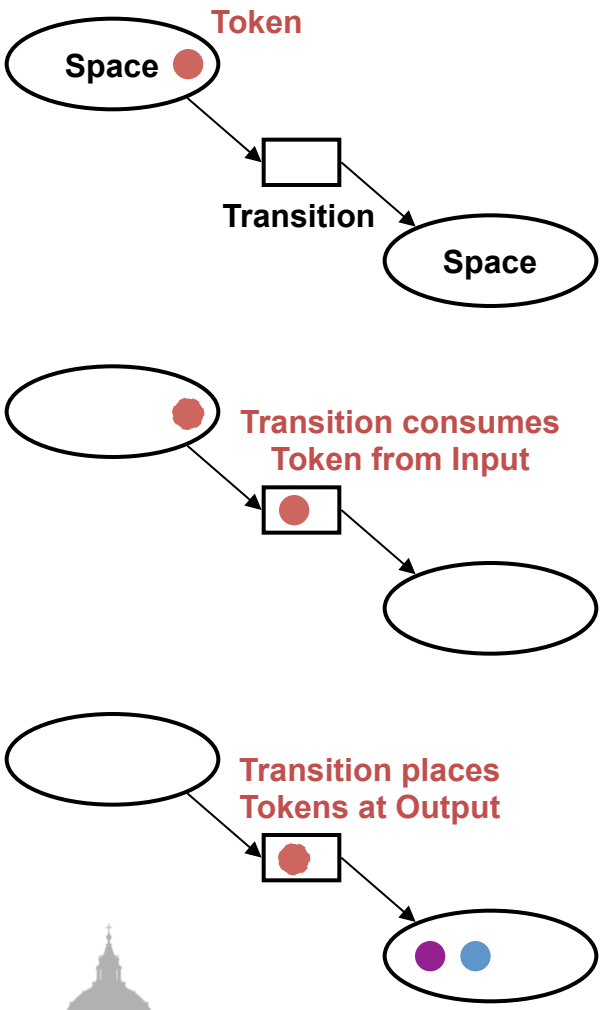
- "Enable an engineer to study a joint cognitive system as if they were using circuit schematics to study an electronic system"
  - Building block encapsulating SA in an individual agent
  - Rules for assembling agents into systems & workflows





Underlying notation

- Coloured Petri Nets
  - Spaces hold tokens
    - Up to some capacity
  - Transitions between spaces
    - Consume tokens from inputs
    - Place tokens at outputs
  - Tokens have colour
    - Transitions can operate differently
- Timed Coloured Petri Nets
  - Transitions
    - Have duration
    - May wait for trigger time

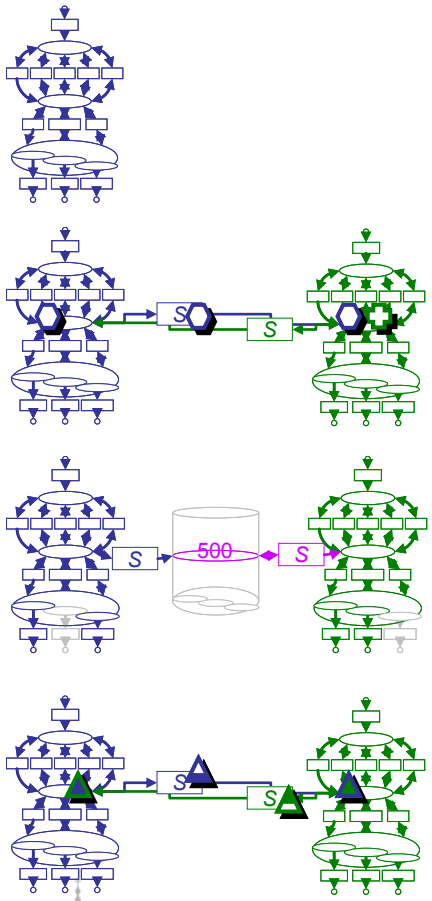


Graphical representation

- SA in an individual agent
- SA across multiple agents
- Architectures for joint cognitive systems

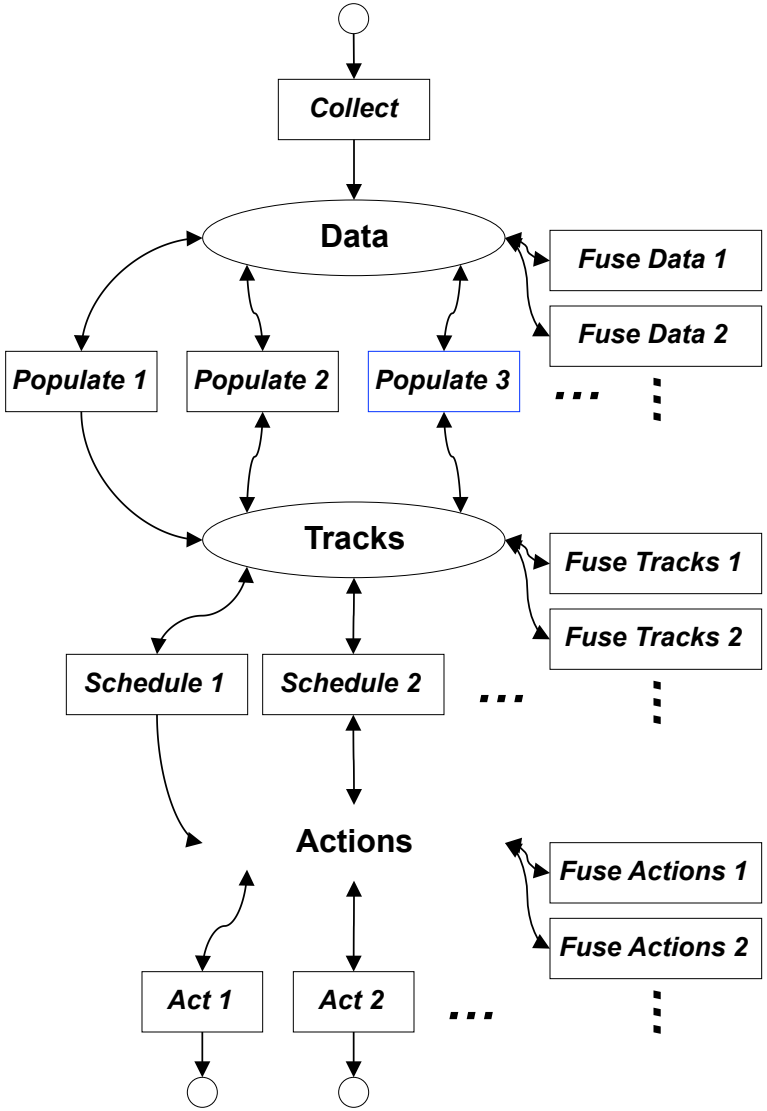
Design patterns

- Schools of thought on fostering SA in joint cognitive systems
  - Individual SA
    - SA is held in a single agent
  - Shared SA
    - Agents have SA over the same tracks
  - Distributed cognition
    - SA is held in mediating artefacts with high storage capacity
  - Compatible SA
    - Agents can have different but compatible perceptions of objects in the environment



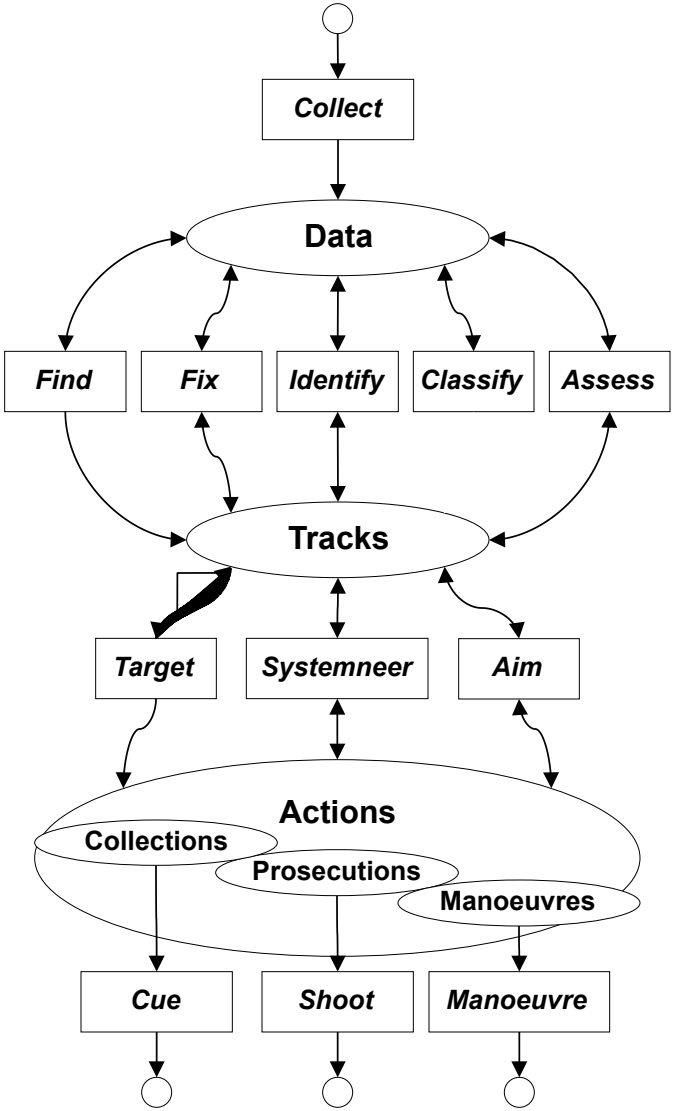
P M Salmon, N A Stanton, G H Walker, D P Jenkins, *Distributed Situation Awareness,* Ashgate 2009.

Building-Block – DTA Agents



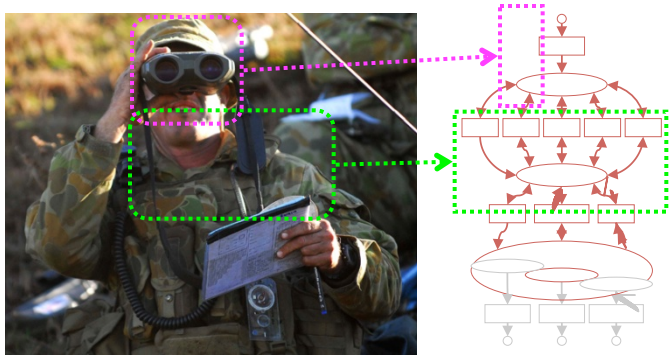
- Collect ***data***
  - *«Location»* at *«Time»* was measured as *«Measurements»*
- Populate ***tracks*** = Situation Awareness
  - Over «*Time Interval*», «*Object*» has / will have «*Property*» with «*Value*»
- Schedule ***actions***
  - [At «*Time*»] [«*Actor Object*»] will «*Act*» [on «*Target Object*»] [using «*Subsystem*»] [directed at «*Location*»]
- Perform actions
- Fusion (data/tracks/actions)

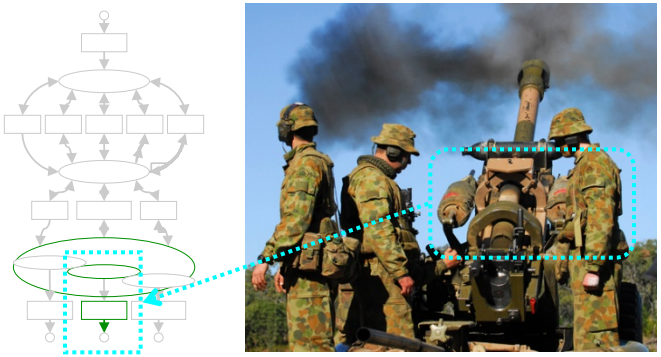
Sensor-Shooter DTA Template



- Specialised tracks
  - Objects in battlespace
- Specialised actions
  - Cueing of sensors
  - Shooting weapons
  - Manoeuvres
- Tracks to actions
  - Target an object
  - Select a system to use
  - Aim at a location × time

Agents implement portions of a DTA Template



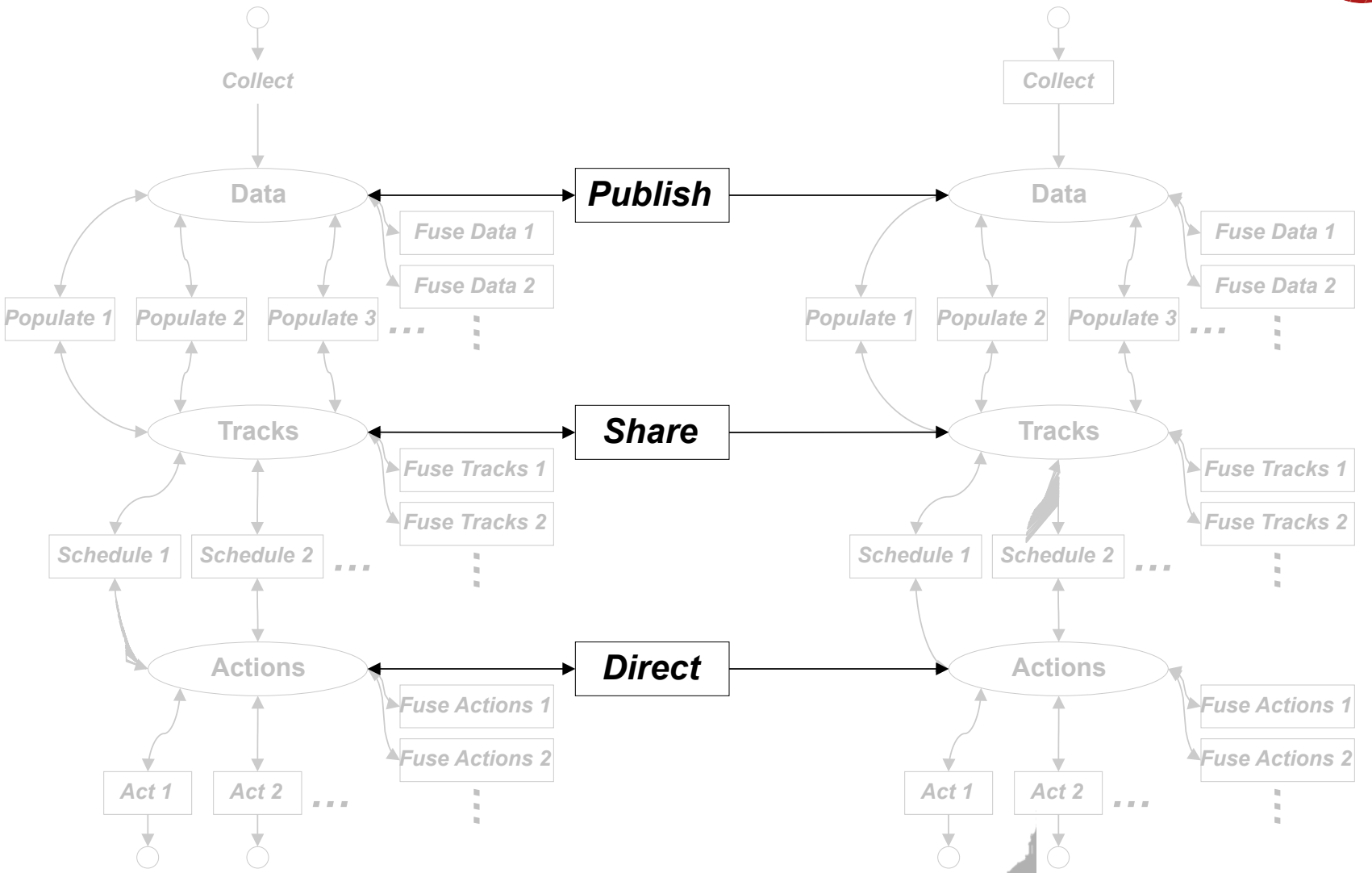


- Soldier
  - Collects data (via eyes, binoculars)
  - Populates tracks on entities
  - Schedule targets for prosecution
- Artillery unit
  - Acts to prosecute

Graphical representation

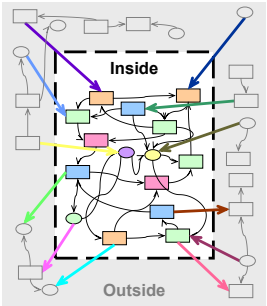
- SA in an individual agent
- SA across multiple agents
- Architectures for joint cognitive systems

Rules for composing DTA Agents

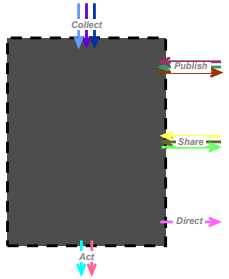


Principles for modelling real-world systems

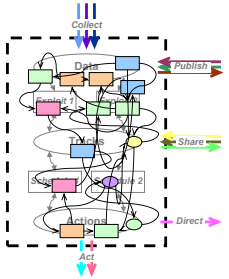
- Identify system boundaries and cross-boundary transactions
  - Free Body Diagram



- Match cross-boundary transactions to DTA composition rules
  - Black Box Analysis

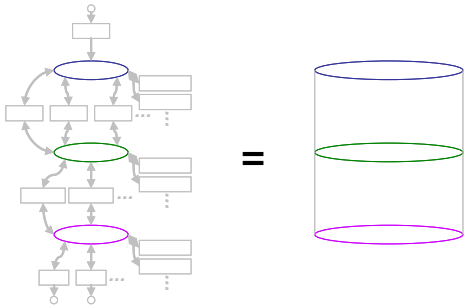


- Match internal processes with DTA template
  - White Box Analysis

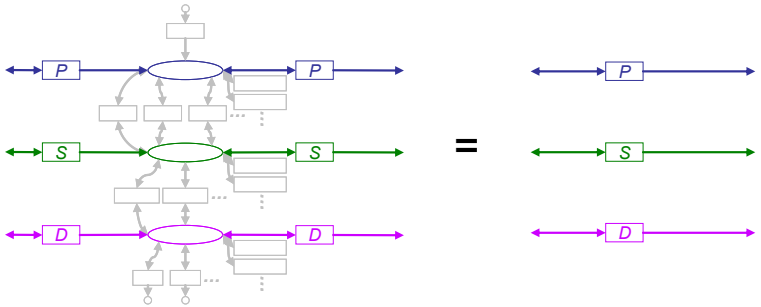


Special cases

- Storage-only agent
  - Stores information but does not process it



- Relay agent
  - Show the agent in full if it is *persistent*
  - Show only the transaction if it is *non-persistent*



Persistent Non-persistent

Graphical representation

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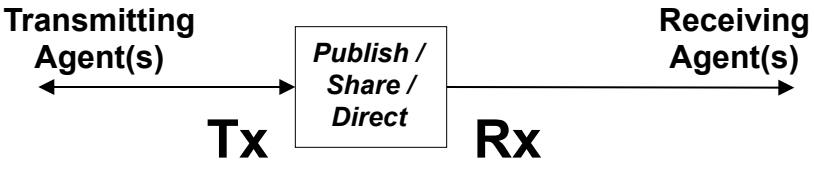
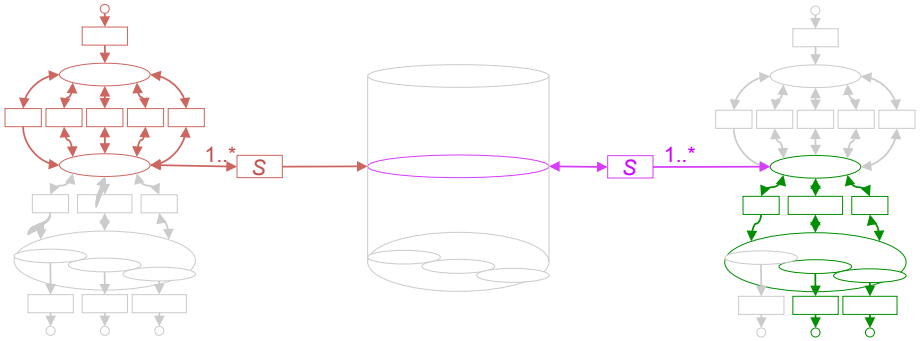


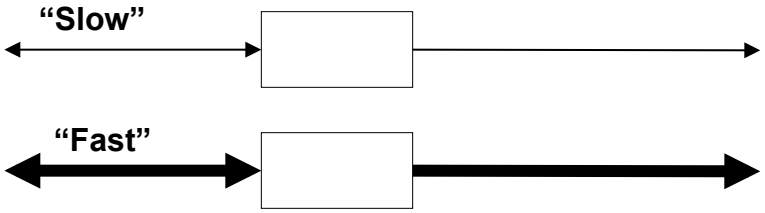
- **1** Exactly 1 agent (default)
- **1…#** Up to # agents

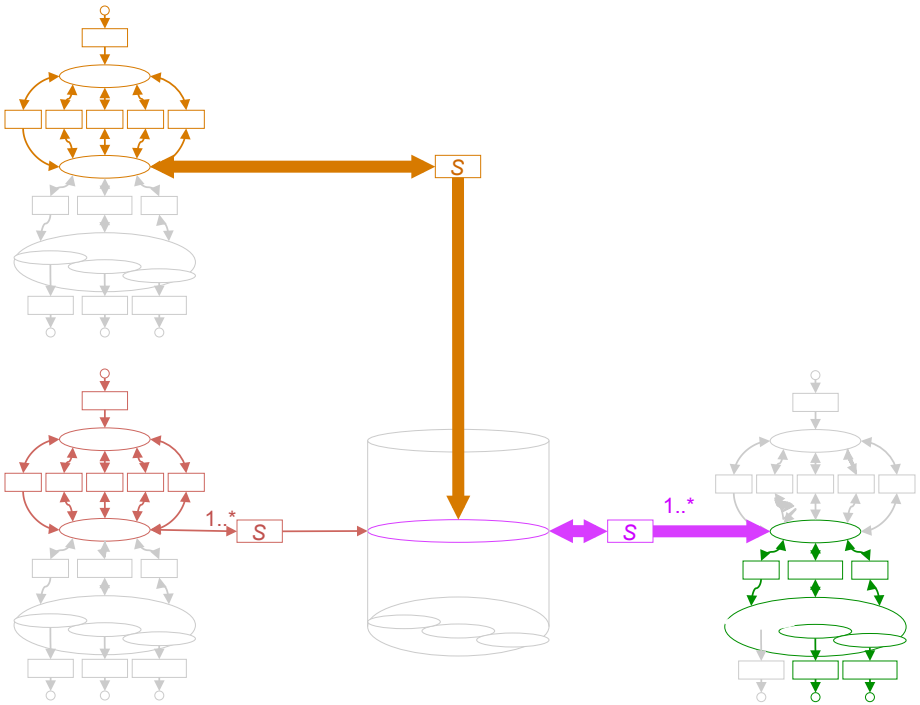
  Arbitrarily many agents
- (and must have Tx = 1 or Rx = 1)



1…* agents shares tracks with 1 agent (storage-only), which shares with 1…* agents

Speed & Tempo





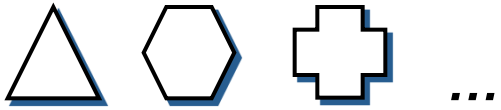
- ***Line thickness*** denotes speed and/or tempo
  - Transitions that occur quickly (*high speed*)
  - Transitions that occur frequently (*high tempo*)

1 agent shares tracks at high tempo and

1…* agents shares tracks at slow tempo

with 1 agent (storage-only), which shares in fast time with 1…* agents

Different Data



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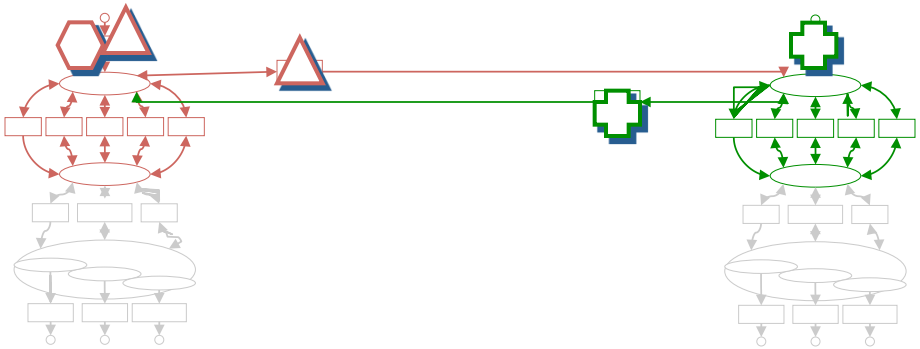
- ***Data Icons*** denote different data



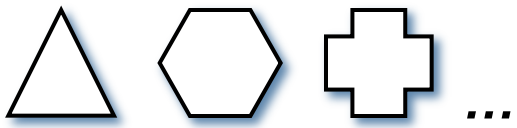
Agent collects

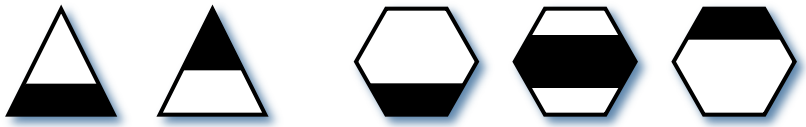
Agent collects

are published

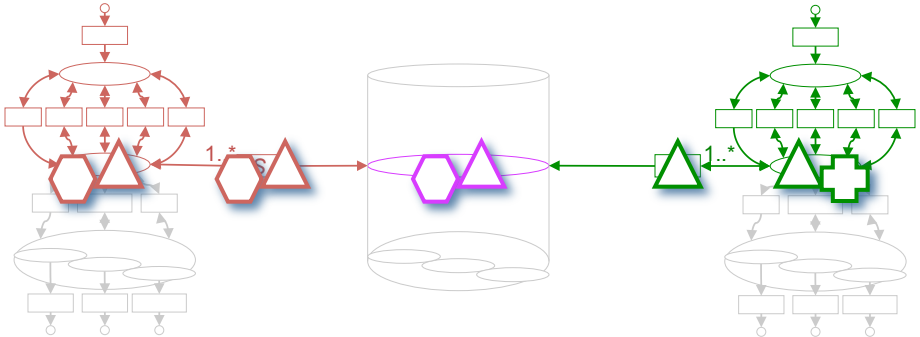
is not published

Different Objects / Properties

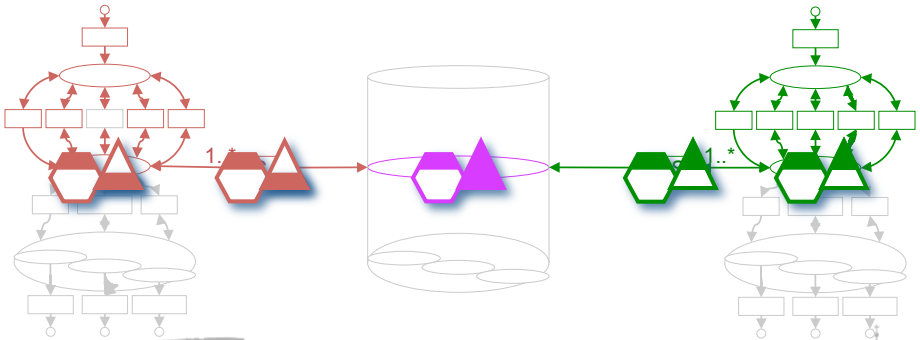




- ***Track Icons*** denote different [classes of] object
- ***Bands*** denote different properties of tracks

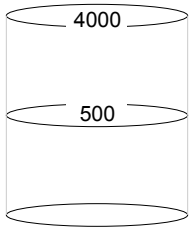


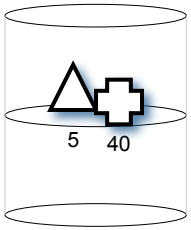
Sharing tracks on ⬡ △
Tracks on ✚ are not shared



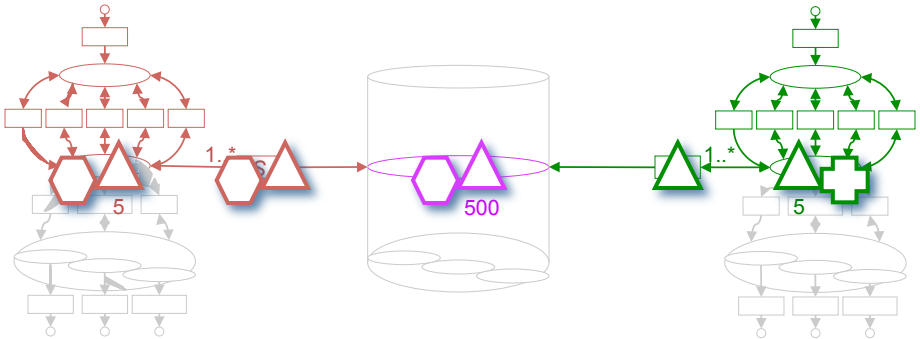
Sharing same property of ⬡
Sharing different properties of △

Storage Capacity

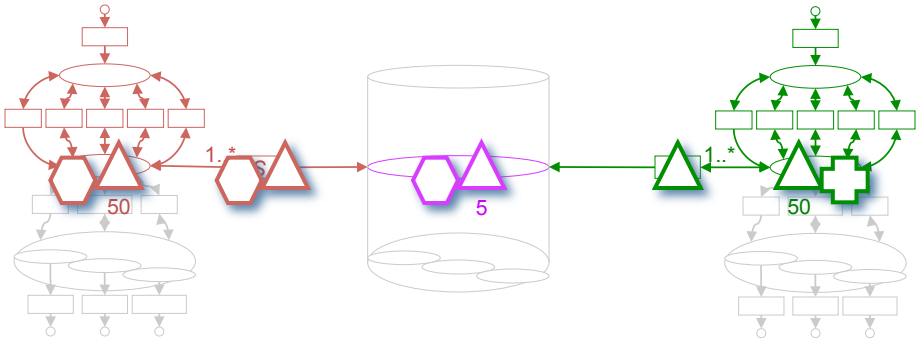




- ***Annotations*** for number of tokens that can be held



Bulk of △ are stored in the central agent



Bulk of △ are stored in the edge agents

Case Study

- Field artillery
  - Cannon, rockets, mortars
  - Modern operations characterised by *indirect fires*
    - Artillery does not have direct line-of-sight to the target
    - Inherently networked, invites improvement via digital-tempo systems

Options and opportunities from BMS-F?

(Battle Management System – Fires)

Baseline System

Joint Fires Team

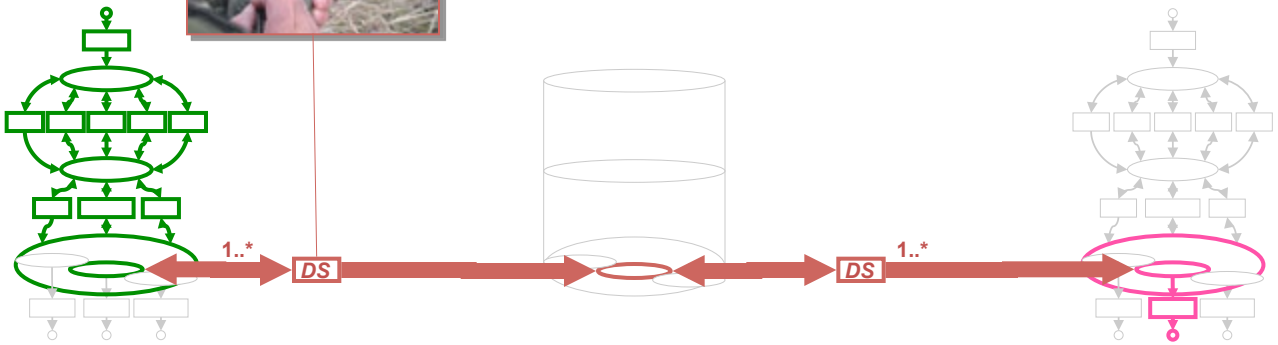
Voice over Radio

Indirect Fire Asset

Voice Time

Digital Call for Fires

Digital Call For Fires via specialised equipment



Joint Fires Team

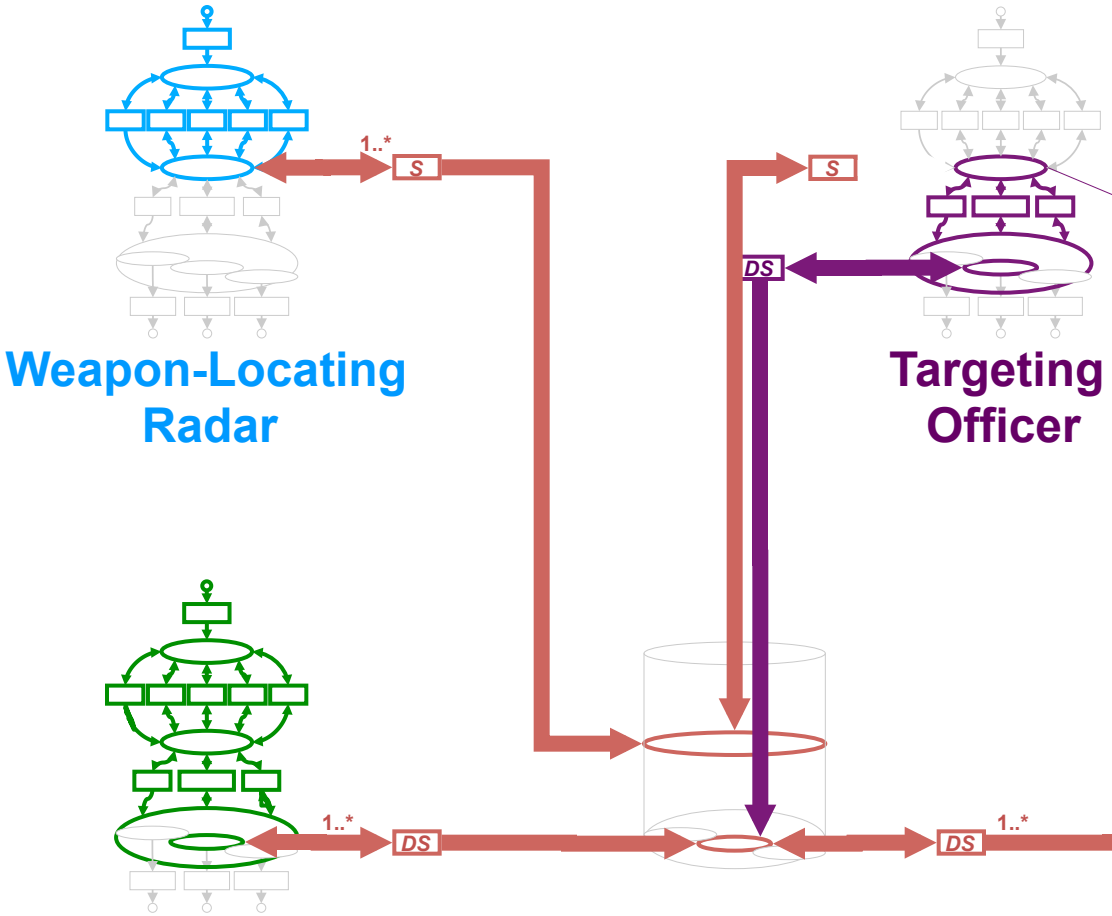
Battle Management System – Fires

Indirect Fire Asset

Voice Time

Digital Time

Near Real-Time Analysis



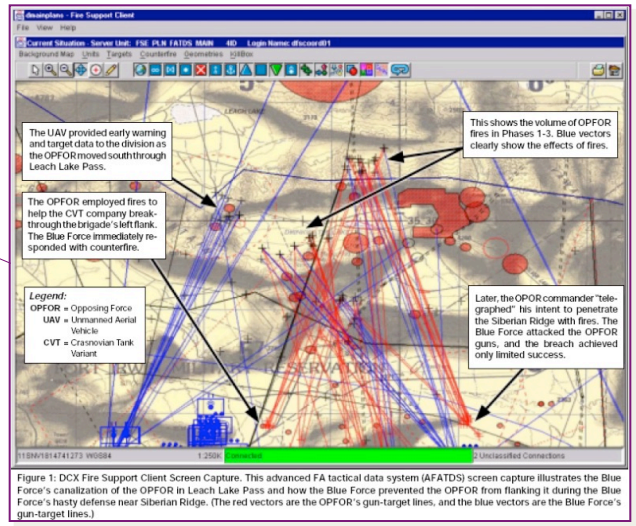


Figure 1: DCX Fire Support Client Screen Capture. This advanced FA tactical data system (AFATDS) screen capture illustrates the Blue Force's canalization of the OPFOR in Leach Lake Pass and how the Blue Force prevented the OPFOR from flanking it during the Blue Force's hasty defense near Siberian Ridge. (The red vectors are the OPFOR's gun-target lines, and the blue vectors are the Blue Force's gun-target lines.)

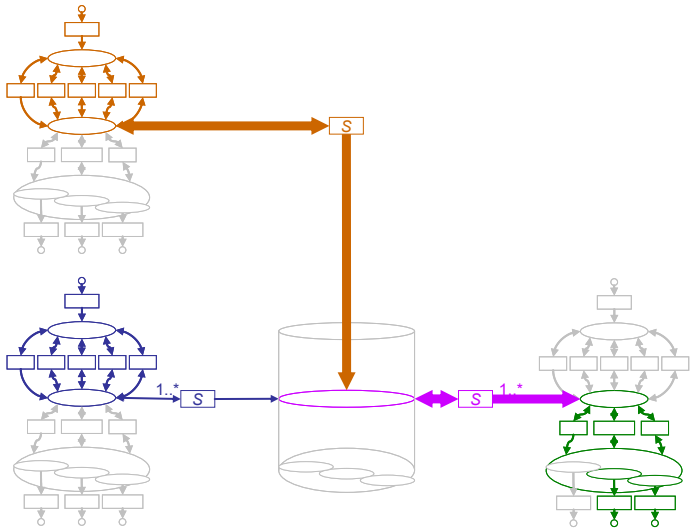
Near real-time analysis of enemy dispositions and actions

Voice Time

Digital Time

Conclusion

- Charting of joint cognitive systems (humans & machines) to examine:
  - Where is situation awareness being held (or lost)?
  - How is situation awareness used in the system's workflows?
  - How can we make improvements (via design, technology)?



- Applied to systems engineering the Australian Defence Force for Network-Centric Warfare

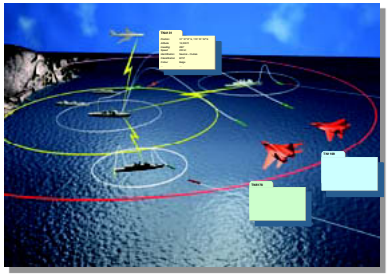
DTA Agent embeds Endsley model of SA

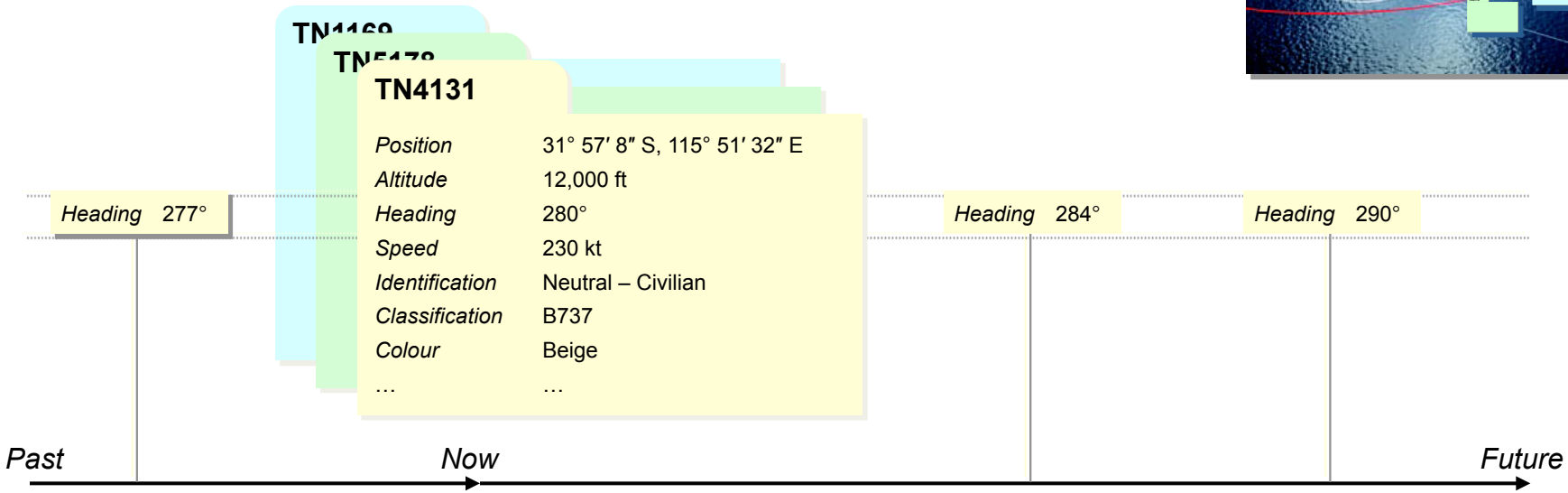
Perception of elements in current situation

Level I «*Object*»

Tracks

Over «*Time Interval*», «*Object*» has / will have «*Property*» with «*Value*»





Comprehension of current situation

Level II «*Property*» **with** «*Value*»

Projection of future status

Level III «*Time Interval*»

Endsley, Mica R. 1995. Toward a Theory of Situation Awareness in Dynamic Systems. *Human Factors* 37 (1):32-64.