Measuring Team Coordination in Complex Sociotechnical Systems: Dynamical Systems Approach

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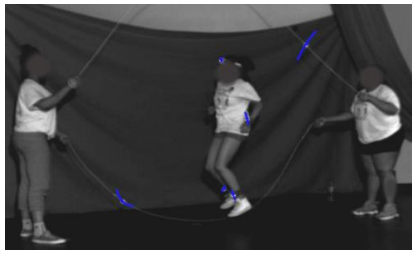
Multi-Vehicle Control Working Group Kickoff Meeting

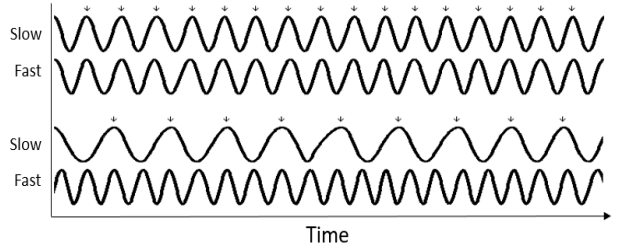
Dynamical Systems Classification of Teamwork: Examples

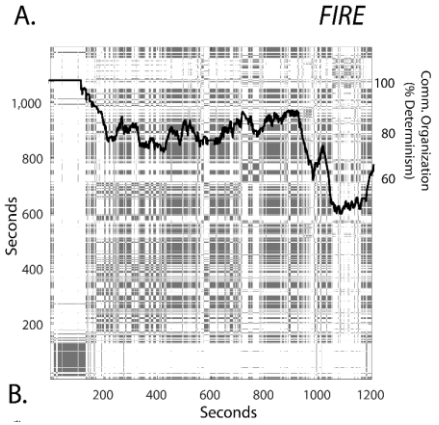
- Rowing (Rhythmic, Monofrequency)
- Double Dutch (Rhythmic, Multifrequency)
- Medical (Complexity)
- Command-and-control (Complexity)
- Problem-solving (Complexity)
- Multi-Vehicle Control (Complexity)

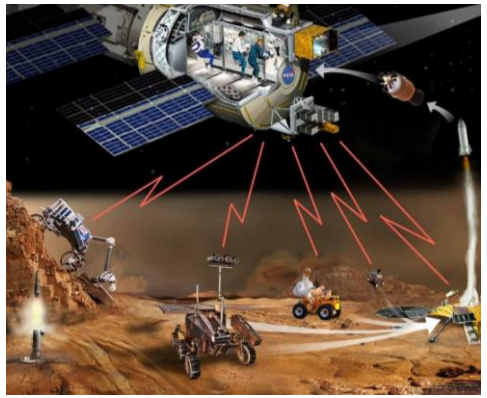
Points←→Cycles/Rhythmic←→**Complex**←→Chaotic

Wolfram







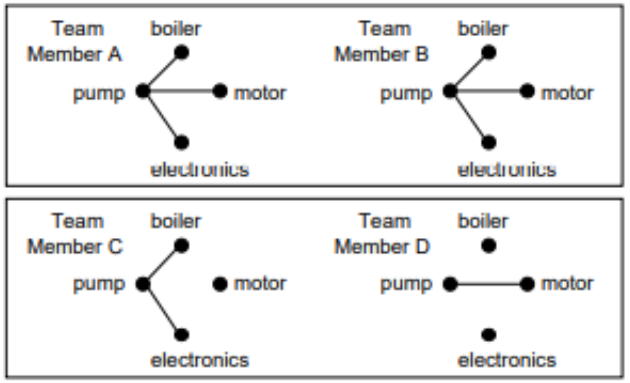


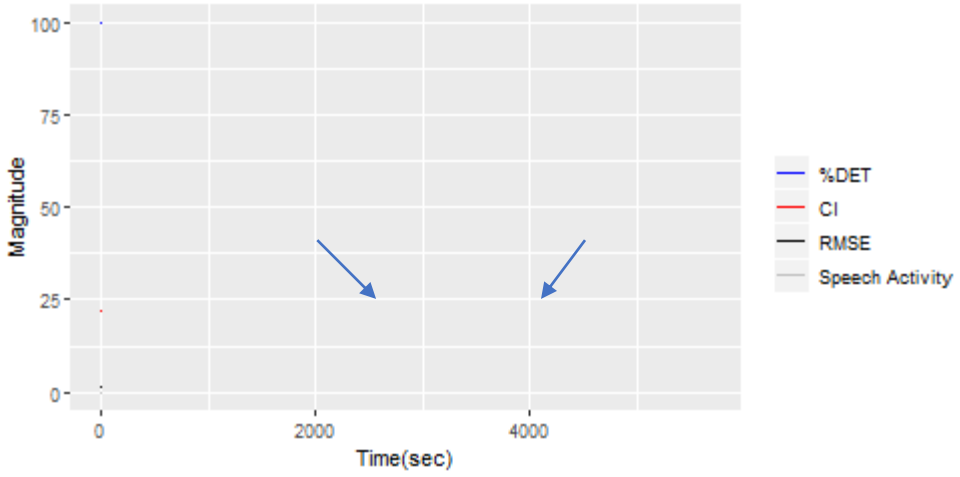
Credit: NASA Goddard Flight Center

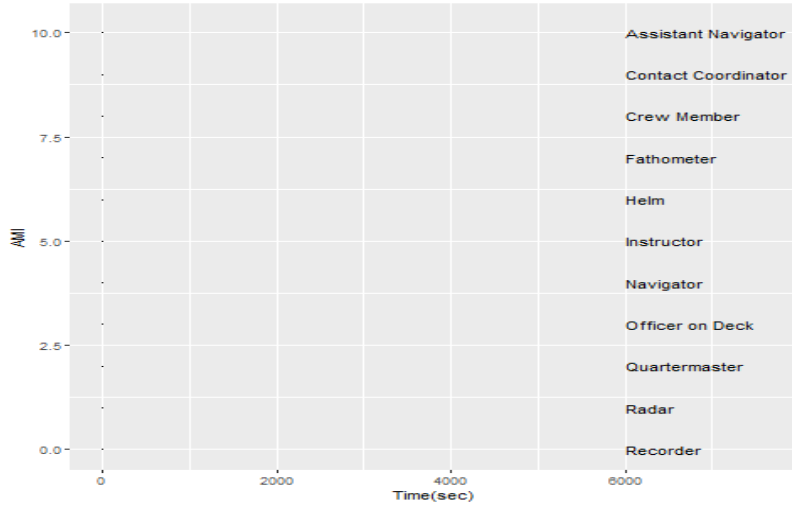
Interactive team cognition and team dynamics (Cooke, Gorman, Myers, & Duran, 2013; Gorman, 2014)

- Team cognition is…
  - Continually varying
    - It is an activity, not a product
  - Highly context-sensitive
  - Should be measured at the team level

From static measures →
Dynamic interaction measures



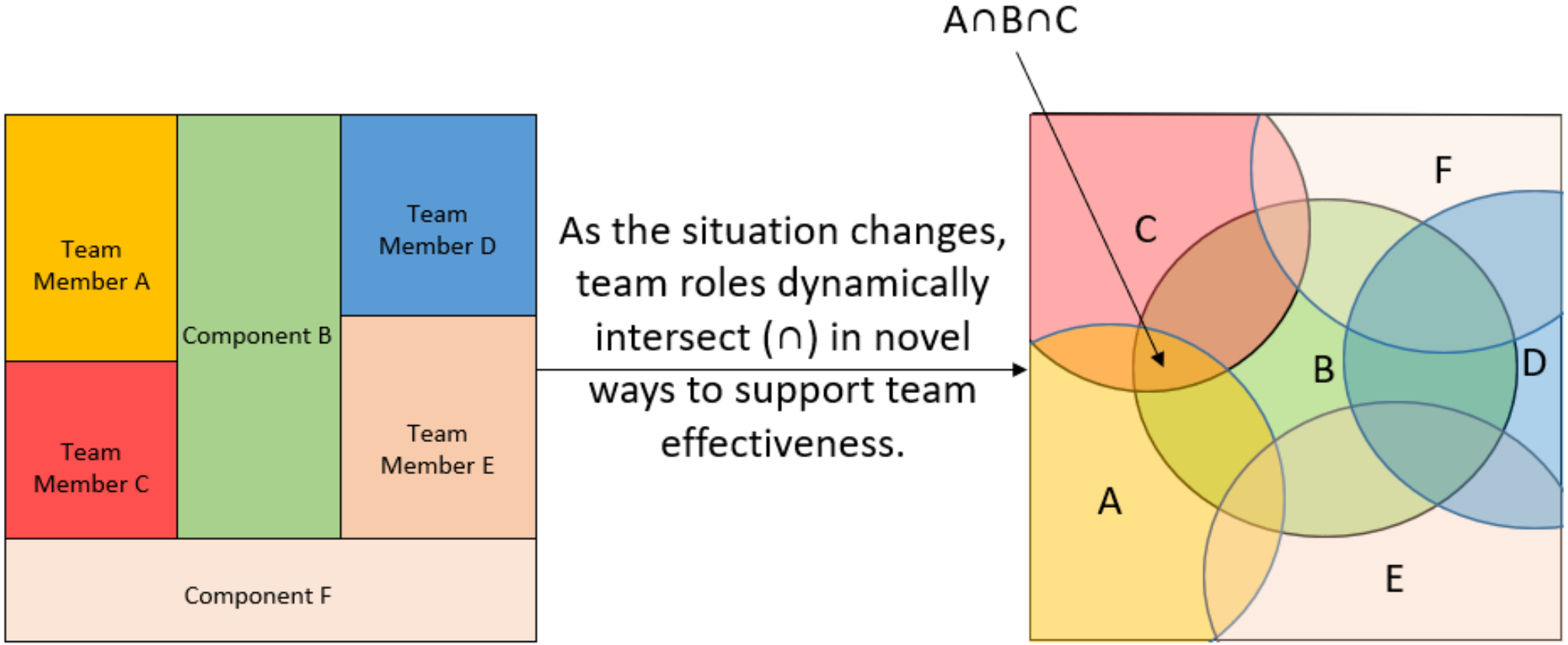




1.	Skilled teams quickly assess the current situation by perceiving relevant stimuli in the physical and social environment and coordinating this perception across relevant team members in order to **enact** a coordinated team response (Gorman, Cooke, & Winner, 2006).
2.	Skilled teams exhibit **situation awareness** by choosing an action that best fits the current situation by behaving in similar but non-identical ways. This requires a flexible team response that is perhaps similar to, but not identical with, responses used in the past (Gorman, Cooke, & Amazeen, 2010).
3.	Skilled teams have consistent behavior in similar (routine) situations but **adapt** their coordination patterns rapidly and appropriately in novel, non-routine situations (e.g., perturbations; Gorman et al., 2010; Gorman et al., 2020).
4.	Skilled teams quickly return to pre-challenge status following a novel, non-routine event, such that they are **resilient** and quick to recover in order to encounter the next challenge (Grimm, Demir, Gorman, & Cooke, 2018).
5.	Skilled teams have a repertoire of **adaptation mechanisms** through which characteristics 1-4 are expressed (e.g., leadership emergence; dynamic role restructuring; Gorman et al., 2020).

Generalizable Characteristics of Cognitively-Skilled Teams

Thelen (2000); Gorman, Dunbar, & Grimm (2018); Gorman et al. (2020)



Modeling Approach that Captures Adaptive and Novel Team Reorganizations (MECE = Mutually Exclusive, Collectively Exhaustive)

McChrystal et al. (2015). *Team of Teams.*

Layered Dynamics

Gorman, Demir, Cooke, & Grimm (2019). *Ergonomics.*

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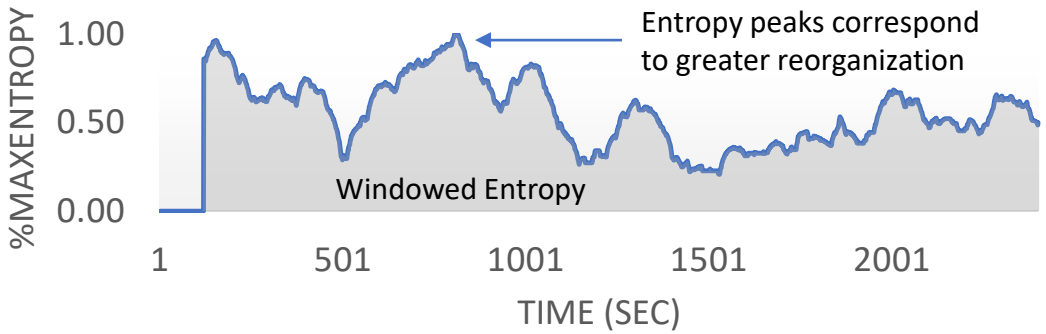
Amount of System Reorganization/Adaptive Capacity

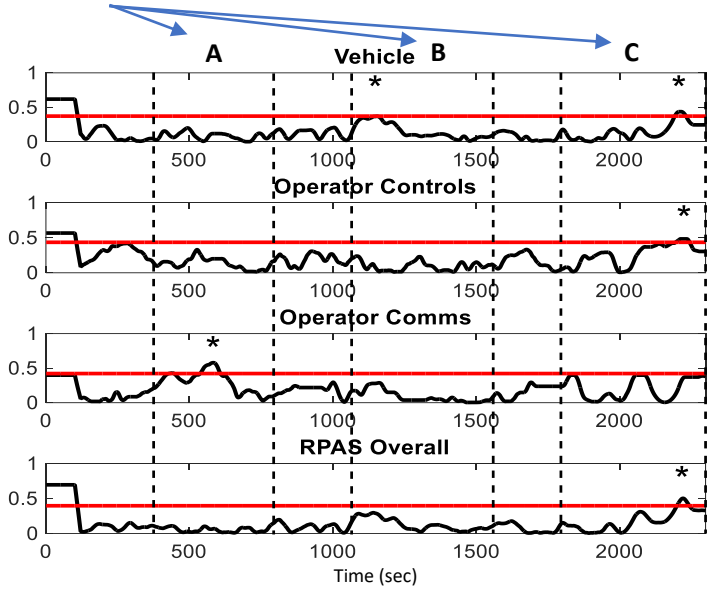
System Component	Sample # (e.g., 1 Hz)					
	1	2	3	4	5	6
1 (q_1)	000	000	100	100	000	000
2 (q_2)	000	010	010	000	010	010
3 (q_3)	110	110	110	000	000	000
4 (q_4)	000	000	000	001	001	001
Binary System State (**Q'**)	000000110000	000010110000	100010110000	100000000001	000010000001	000010000001
Decimal System State (**Q'**)	48	176	2224	2049	129	129

Sliding Window

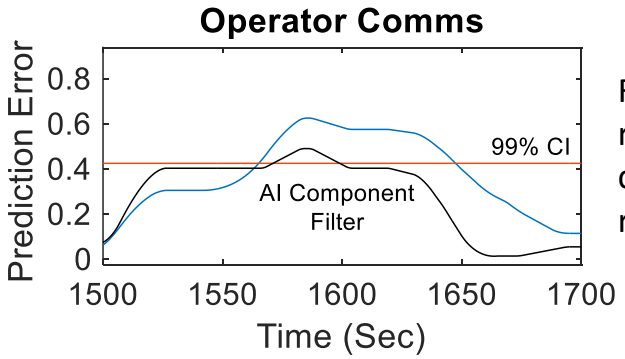
Calculate amount of reorganization across system states each time window is updated



Perturbations

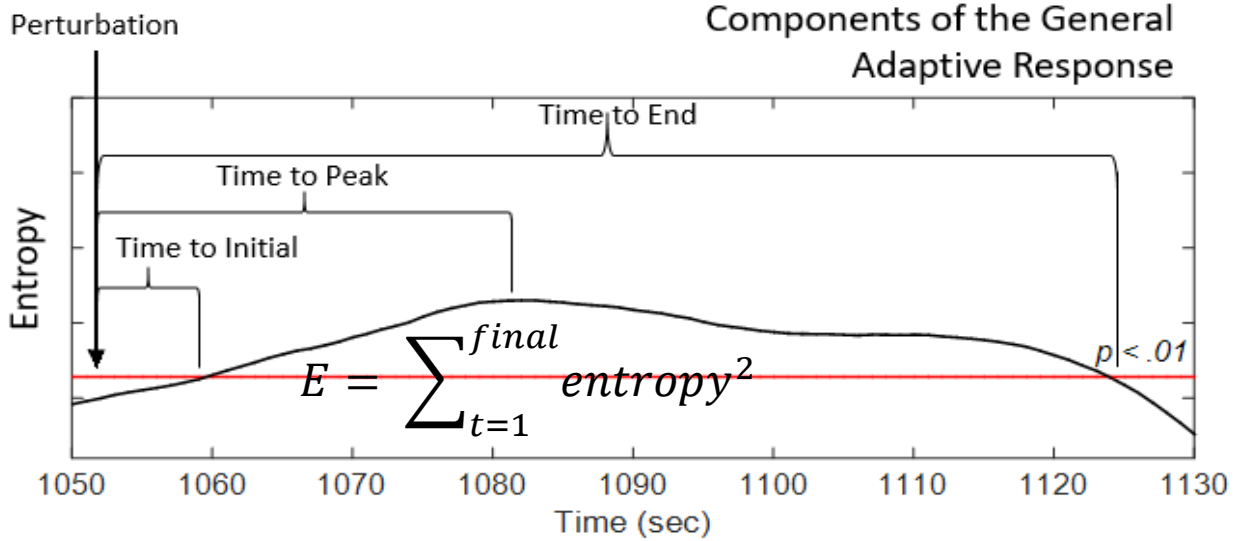


A – automation failure
B – autonomy failure
C – malicious cyberattack



Filtering out components reveals how much each contributes to system reorganization

Real-time measurement of **enaction**, **adaptation**, and **resilience**



Metric	Definition	Characteristic
Time to initial redline entropy	Time to reach a significant level of reorganization	**Enaction**; time taken for a team to begin its reorganization behavior (***Characteristic 1**)
Time to peak redline entropy spike (adaptation time)	Time taken to reach greatest amount of reorganization	**Adaptation**; time to exhibit greatest amount of reorganization behavior (***Characteristics 2 & 3**)
Time to end redline entropy spike (relaxation time)	Time to return below significant level of reorganization	**Resilience**, recovery; time taken to return to stable levels of reorganization (***Characteristic 4**)

Failure Type	Real-time Dynamics Metrics	Outcome Measure	System Layer	Performance Correlation
Hybrid Failure	RMSE	Target Processing Efficiency (TPE)	Communication	**Enact (r = -.522, p = .011) Adapt (r = -.522, p = .011) Res. (r = -.524, p = .010)**
		Ground Truth Resilience Score (GTRS)	Communication	**Enact (r = .512, p = .012) Adapt (r = .513, p = .012) Res. (r = .513, p = .012)**
System Failure (Power Down)	Entropy	Target Processing Efficiency (TPE)	System	**Enact (r = -.395, p = .028) Adapt (r = -.400, p = .026) Res. (r = -.394, p = .028)**
		Ground Truth Resilience Score (GTRS)	Control	**Enact (r = -.389, p = .031)**
Malicious Attack	Entropy	Team Performance (Mission Level)	Vehicle	**Enact (r = -.521, p = .003) Adapt (r = -.532, p = .002) Res. (r = -.437, p = .016)**
	RMSE	Ground Truth Resilience Score (GTRS)	Communication	**Enact (r = .521, p = .013) Adapt (r = .520, p = .013) Res. (r = .509, p = .016)**
			System	**Enact (r = -.464, p = .010) Adapt (r = -.466, p = .009) Res. (r = -.468, p = .009)**

Grimm (2020)

What combination of team components contributes the most to adaptive responses?

AMI = how much knowledge of each component's activities reduces our uncertainty in team (system) state

System Component	Sample # (e.g., 1 Hz)					
	1	2	3	4	5	6
1 (q_1)	000	000	100	100	000	000
2 (q_2)	000	010	010	000	010	010
3 (q_3)	110	110	110	000	000	000
4 (q_4)	000	000	000	001	001	001
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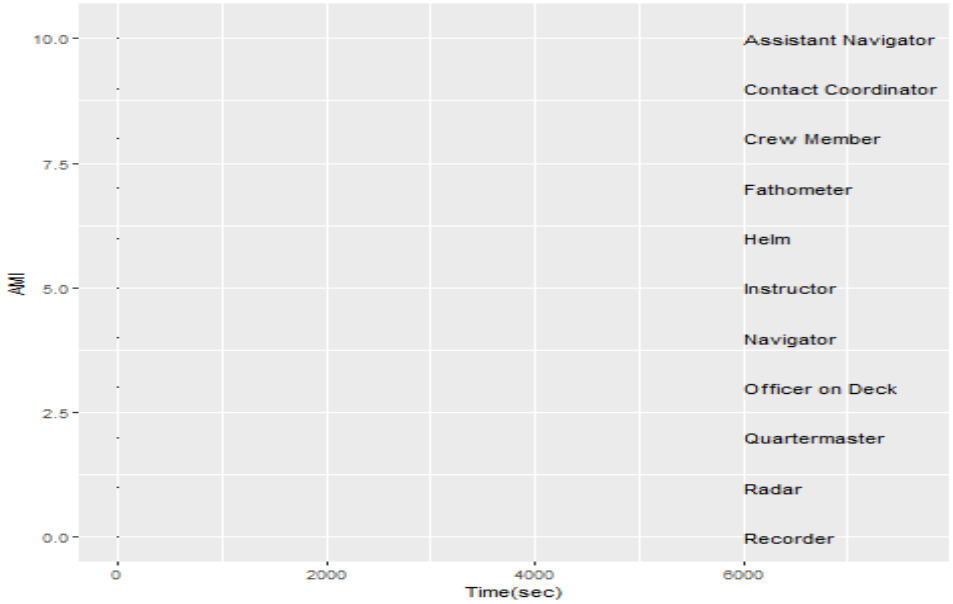

Gorman, Grimm, Stevens et al. (2020). *Human Factors.*

Figure 2

File Edit View Insert Tools Desktop Window Help

	Frequency Count	Frequency %
MD1 to MD2/RN1/CN1/Tech1	145	6.6422
RN1 to MD1/MD2/CN1/Tech1	130	5.9551
Unknown	110	5.0389
MD2 to MD1	67	3.0692
Tech1 to MD1	66	3.0234
MD1 to RN1/CN1	61	2.7943
RN1 to CN1	60	2.7485
CN1 to MD1/MD2/RN1	56	2.5653
CN1 to MD1/RN1	55	2.5195
Tech1 to MD1/MD2/RN1/CN1	50	2.2904
RN1 to MD1	47	2.1530

Figure 1

File Edit View Insert Tools Desktop Window Help

	Average Mutual Information
MD2 to MD1	0.0053
MD1 to MD2/RN1/CN1/Tech1	0.0036
Tech1 to MD1	0.0033
RN1 to MD1/MD2/CN1/Tech1	0.0025
Unknown	4.3363e-04

Credit: US Air Force

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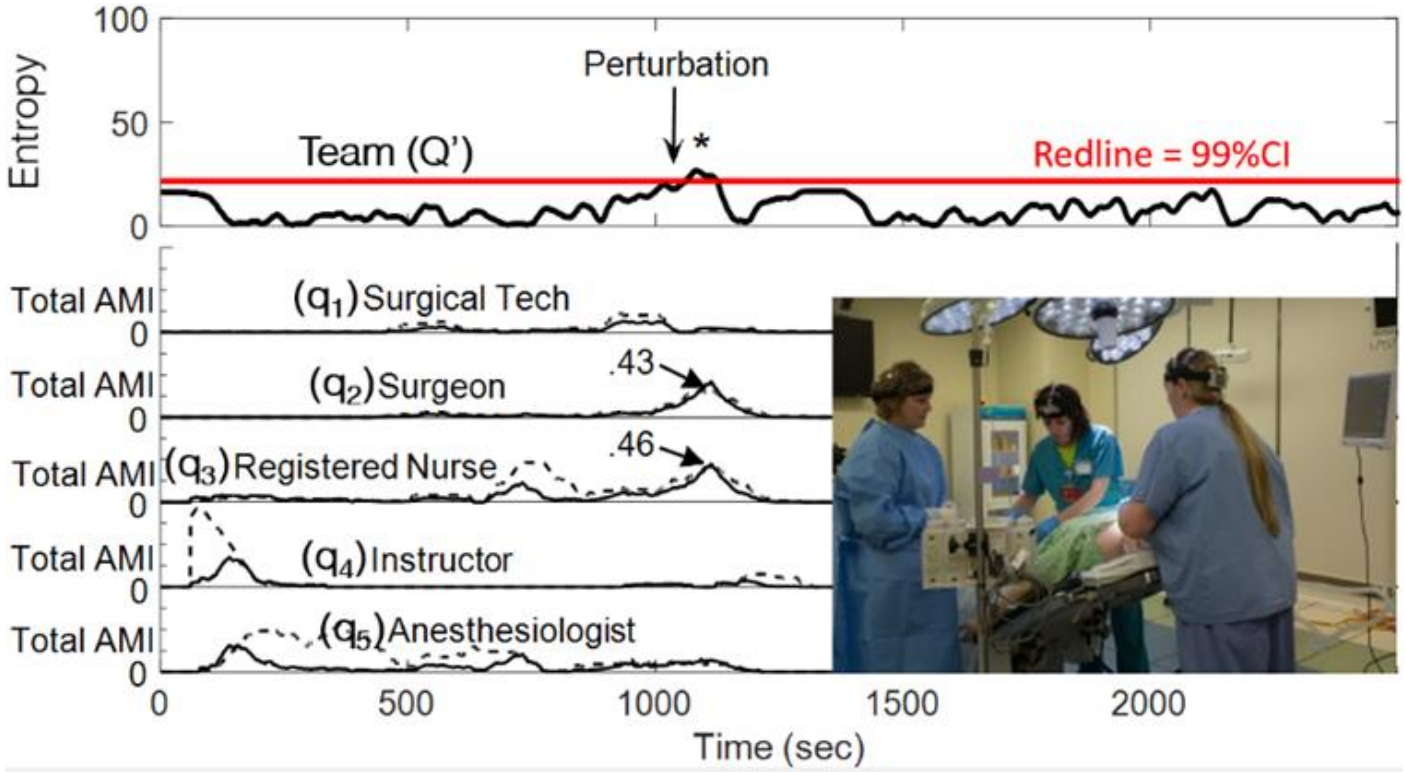
Subsidiarity and Adaptation Mechanisms



- Whereas pre-defined tasks can be completed by following procedures, many tasks require team cognition "on the fly"
- These tasks require dynamic reorganization
- Identify subsidiary system layers where reorganization takes place

Gorman, Grimm, Stevens et al. (2020). *Human Factors.*