SYSTEMS ENGINEERING RESEARCH CENTER

RT-180: Game-theoretic Risk Assessment for Distributed Systems

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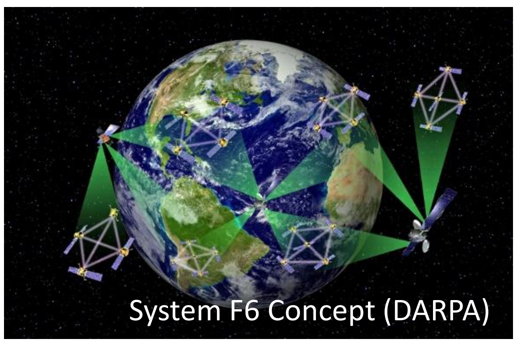
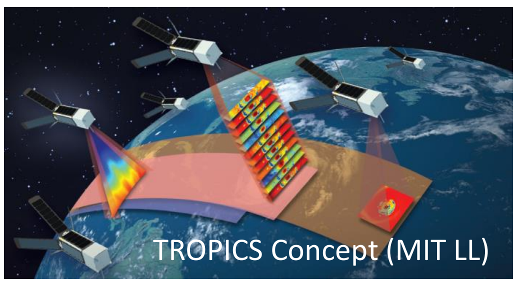
Research Task / Overview

Distributed system architectures

- Upside potential
  - Flexibility, robustness
  - Resource efficiency
- Downside risk
  - Interdependencies
  - Cascading failures
- Frequently described as "robust-yet-fragile" (Alderson & Doyle, 2010)



System F6 Concept (DARPA)



TROPICS Concept (MIT LL)

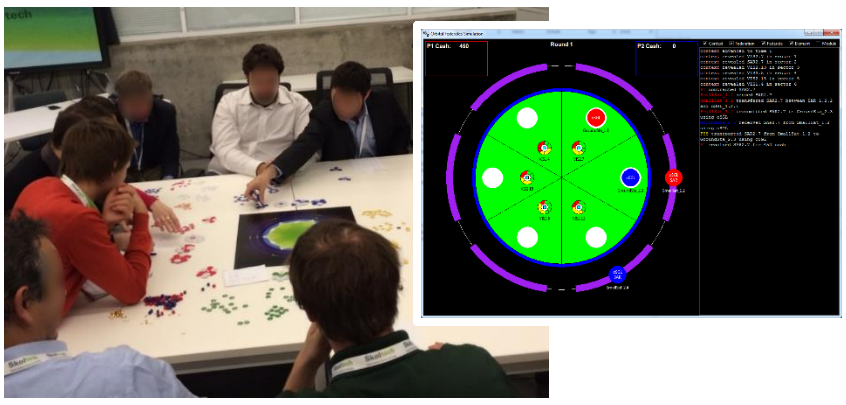
Goals & Objectives

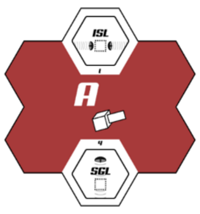
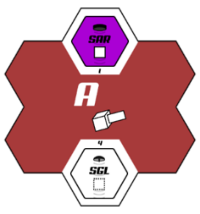
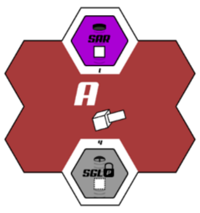
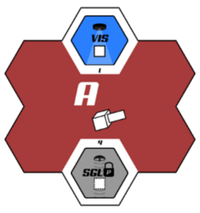
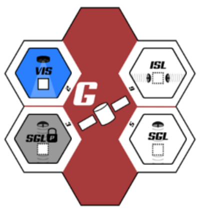
Assess strategic risk of distributed architectures

- Strategic risk (instability, *not* uncertainty) among multiple decision-makers
- Extend Selten's (1995) weighted average log measure (WALM) of risk dominance from 2-player symmetric games in Grogan et al. (2016)

Data & Analysis

- Illustrative use case in *Orbital Federates*
- Simplified game to explore satellite systems (Grogan & de Weck, 2015)
- Python multi-actor value model



	Mono.	Dist. A	Dist. B
P1	 $v_1^{\phi} = 0$	 $V_1(d_1) = -1100$ $V_1^{\psi}(d_1, d_2) = -572$ $V_1^{\psi}(d_1, d_3) = -653$ $V_1^{\psi}(d_1, d_2, d_3) = 100$	 $V_1(d_1) = -104$ $V_1^{\psi}(d_1, d_2) = 83$ $V_1^{\psi}(d_1, d_3) = 33$ $V_1^{\psi}(d_1, d_2, d_3) = 271$
P2	 $v_2^{\phi} = -39$	 $V_2(d_2) = -389$ $V_2^{\psi}(d_1, d_2) = 440$ $V_2^{\psi}(d_2, d_3) = -255$ $V_2^{\psi}(d_1, d_2, d_3) = 536$	 $V_2(d_2) = -288$ $V_2^{\psi}(d_1, d_2) = 141$ $V_2^{\psi}(d_2, d_3) = -288$ $V_2^{\psi}(d_1, d_2, d_3) = 150$
P3	 $v_3^{\phi} = 30$	 $V_3(d_3) = -320$ $V_3^{\psi}(d_1, d_3) = 386$ $V_3^{\psi}(d_2, d_3) = -158$ $V_3^{\psi}(d_1, d_2, d_3) = 639$	 $V_3(d_3) = -220$ $V_3^{\psi}(d_1, d_3) = 391$ $V_3^{\psi}(d_2, d_3) = -161$ $V_3^{\psi}(d_1, d_2, d_3) = 378$

$R_\psi = 0.80 \quad R_\psi = -0.46$

Methodology

	Hare (ϕ)	Stag (ψ)
Hare (ϕ)	2, 2	4, 0
Stag (ψ)	0, 4	5, 5

$R_\psi = \ln 2 \approx 0.69$

Stag hunt by Gaston Phoebus (Bibliotheque Nationale de France)

Weighted average log measure (WALM):

$$R_\psi = \sum_{i=1}^{n} w_i(A) \ln\left(\frac{u_i}{1-u_i}\right)$$

$R_\psi > 0$: ϕ is "risk dominant"

$R_\psi < 0$: ψ is "risk dominant"

Future Research

- Assess "linear incentives" assumption: there are increasing returns to scale
- Understand how to practically but rigorously quantify deviation losses u_i
- Develop application case in the context of real-world distributed system
- Assess WALM of multiple architectures

Contacts/References

D.L. Alderson and J.C. Doyle, "Contrasting views of complexity and their implications for network-centric infrastructure," *IEEE Trans. on Systems, Man, and* Cybernetics, 40(4):839-852, 2010.

P.T. Grogan, K. Ho, A. Golkar, and O.L. de Weck, "Multi-actor value modeling for federated systems," *IEEE Systems*, 2016. Early access.

P.T. Grogan and O.L. de Weck, "Interactive simulation games to assess federated satellite system concepts," *2015 IEEE Aerospace Conference*, Big Sky, MT, 2015.

R. Selten, "An axiomatic theory of a risk dominance measure for bipolar games with linear incentives," *Games and Economic Behavior*, 8(1):213-263, 1995