Architectural Patterns for Self-Organizing Systems-of-Systems

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Overview

- Introduction
- Self-Organization
  - Definitions
  - Characteristics
- Systems-of-Systems
- Self-organizing examples
- Self-organizing patterns
- Conclusions
- Q&A?

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Purpose

Establish a basic understanding of self-organization within an SoS context, suggest a set of necessary self-organizing characteristics, and identify candidate architectural patterns, which can be used to address contemporary challenges.

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Why do we care?

- Contemporary adversaries

  intelligent, multi-agent, self-organizing, systems-of-systems with swarm intelligence, tight learning loops, fast evolution, and dedicated intent

- Broad capability needs
- Benefit of SE principles and evolutionary delivery
- Systems Engineering Guide for Systems-of-Systems
  - Developing and evolving SoS architecture
  - Monitor and assess change

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SAREPH

Architectural principles for agile design

- **S**elf-organizing
- **A**daptable Tactics
- **R**eactive Resilience
- **E**volving Strategies
- **P**roactive Innovation
- **H**armonious Operation

Most important and necessary characteristic

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Self-Organization Defined

- *increased order where internal organization becomes more complex without outside intervention*
- *the generation of global structure resulting from positive and negative feedback of local interactions of independent agents*
- *adaptation of one's structure to fit the environment*

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Self-organizing Characteristics

- Common purpose—the primitive needs that motivate actions
- Conditional dependency—dependency driven through interconnectivity of participants
- Situation awareness—perception, correlation, projection
- Adaptability—readily capable to adjust
- Autonomy—ability to make independent decisions
- Whole-part relationship—belonging to something bigger

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Systems-of-Systems

a set or arrangement of systems that results from independent systems integrated into a larger system that delivers unique capabilities

- Systems with independent purpose
- Systems with complimentary capabilities
- Higher-level objective(s)
- New relationships (organizational & structural)
- Unique behavior emerges

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Ushahidi

- 2007 Kenya Election
- Subsequent crisis developed
  rioting, ethnic attacks, and general anarchy
- Ory Okolloh identified the need
  - Independent *testimony* from populace
  - Volunteer corroboration
  - Correlation engine
  - Mapped depiction of events

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Ushahidi Characteristics

SO Characteristic	Ushahidi Manifestation
Common Purpose	• Crisis support • Initially to track incidents of violence
Conditional Dependency	• Events reported by local observers • Events verified by volunteers • Relief provided to victims
Situation Awareness	• Local observers report via SMS, email or web • Correlated events reported via web
Adaptability	• Any event can be reported; observer selected • Adapted to any crisis e.g. 2010 Gulf spill
Autonomy	• Local observers decide when and what to report • New deployments take minimal time
Whole-Part Relationship	• Inherent in SoS

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Swarm Robotics—Mine Sweepers

- Large numbers of small robots
- Each has simple capabilities
- Each exhibits independent decisions
- Coordination
  - Rules of engagement
  - Communication (e.g. SRR & LRR)
- Emergent swarm behavior (group effort)

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Swarm Robotics Characteristics

SO Characteristic	Swarm Robotics Manifestation
Common Purpose	• Locate and disarm all mines in a given area
Conditional Dependency	• Operational behavior or rules of engagement; robots must respond to recruitment messages
Situation Awareness	• Short Range Recruitment messages • Long Range Recruitment messages
Adaptability	• Robust with respect to individual robot failures
Autonomy	• Independent robotic decisions; robots randomly search and independently respond
Whole-Part Relationship	• Inherent in SoS

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SOLE

- Research by Sugata Mitra
  - Hole in the Wall Project
  - New Castle biotechnology experiment
  - Gateshead group experiments
- Small group of self-motivated children
- Internet access
- “Granny Cloud”

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SOLE Characteristics

SO Characteristic	SOLE Manifestation
Common Purpose	• Topic of interest • Human curiosity
Conditional Dependency	• Small Groups • “Granny Cloud” • Peer pressure
Situation Awareness	• Computer/Internet
Adaptability	• Internet makes any educational topic possible • Children self-organize small groups “at will”
Autonomy	• Children decide how to learn
Whole-Part Relationship	• Inherent in SoS

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Crowd Sourced Incident Reporting

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Name	Crowd Sourced Incident Reporting (CSIR)
Context	Incident information is needed from a large population potentially scattered across a broad geographic area
Problem	Details of a crisis event are needed, but sending in a team of specialists does not scale and they are subject to the crisis at hand
Forces	• Individuals within the population decide what to report, but their reports may not be relevant or accurate • Succinct relevant information is desired but unconstrained reporting resources leads to numerous reports • Full coverage is desired but the geographic area may be vast and hostile
Solution	Create the ability for the population within the crisis zone to submit first hand witness reports and support the ability to correlate the data
Examples	• Ushahidi • Citizens monitor Gulf Coast after oil spill • Amber Alert

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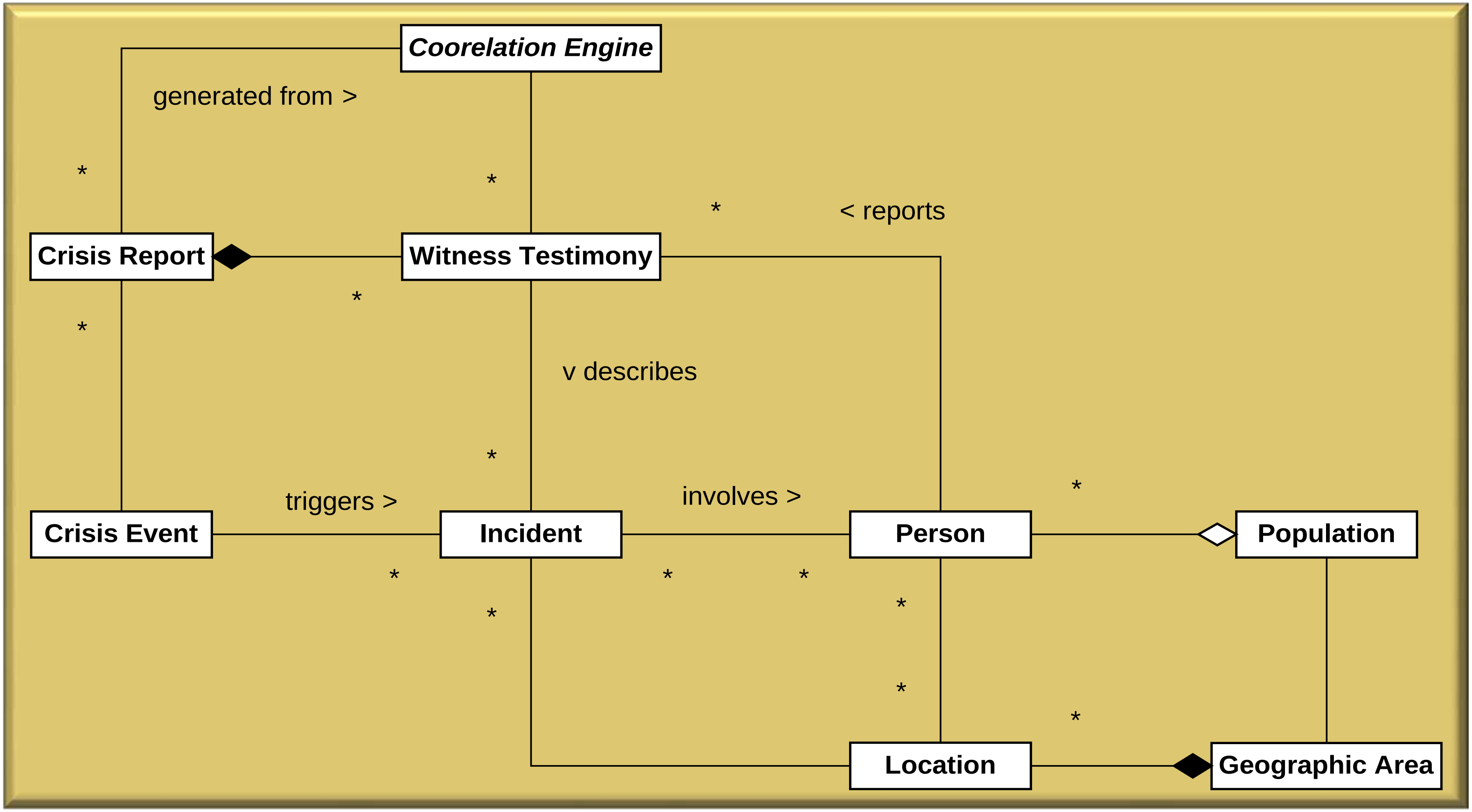
CSIR Static Structure



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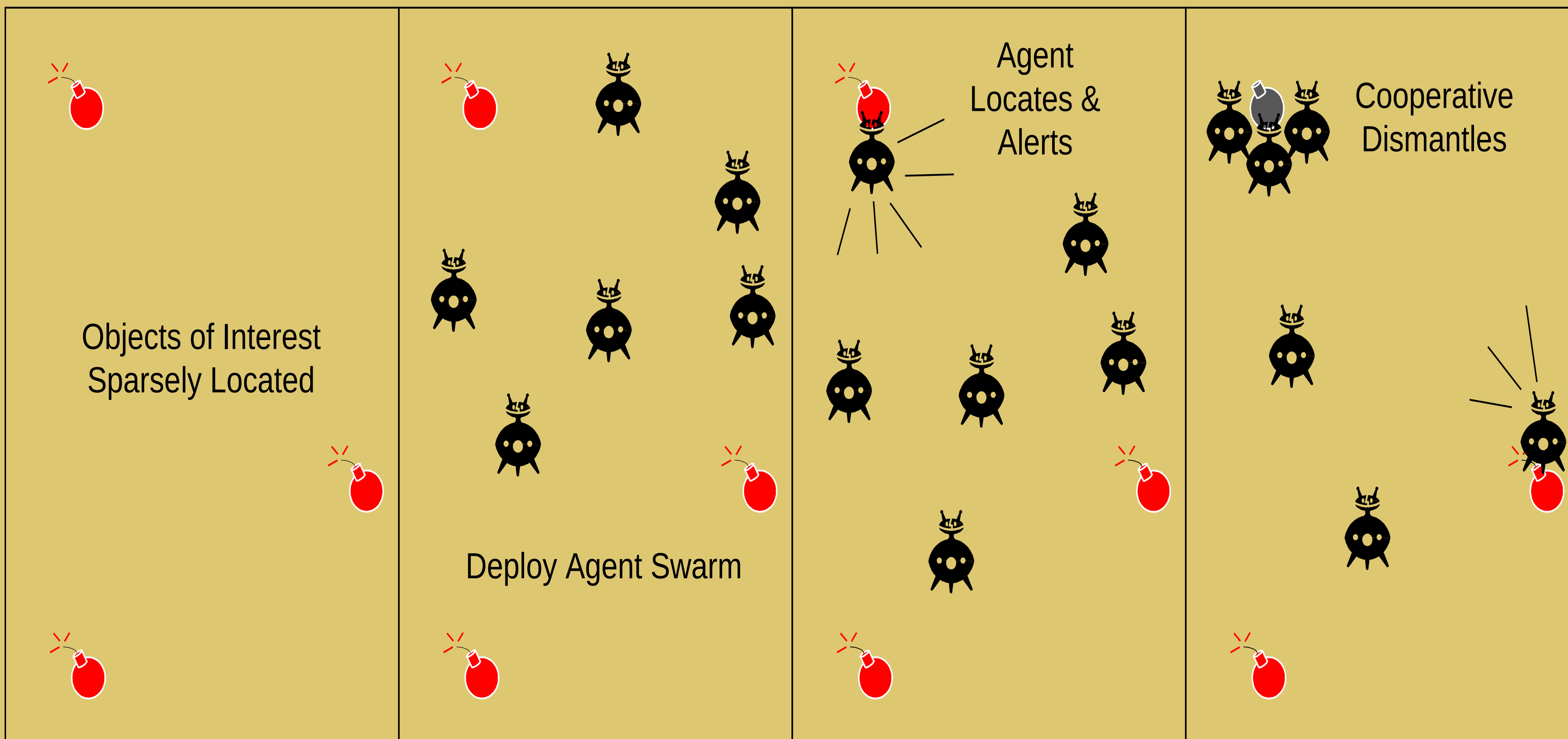
Swarm Discovery & Cooperation



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Name	Swarm Discovery and Cooperation
Context	One or more objects of interest must be located in a sparse environment, and the mission objective cannot be accomplished effectively by any one individual.
Problem	Locate objects in a sparse environment and perform some cooperative operation on them (e.g. transport or disarm).
Forces	• Time pressure to accomplish mission vs. cost of multiple resources. • Time pressure to find an object vs. search area size. • Risk of search-agent loss vs. cost of redundancy.
Solution	Randomly deploy a large number of simple agents across the target space. Each agent searches for the object of interest, which can be detected using individual sensors. Once found, the discovering agent notifies others to assist in actions on the target.
Examples	• Mine detection • Multi-agent search & transport • Search and rescue • Foraging ants

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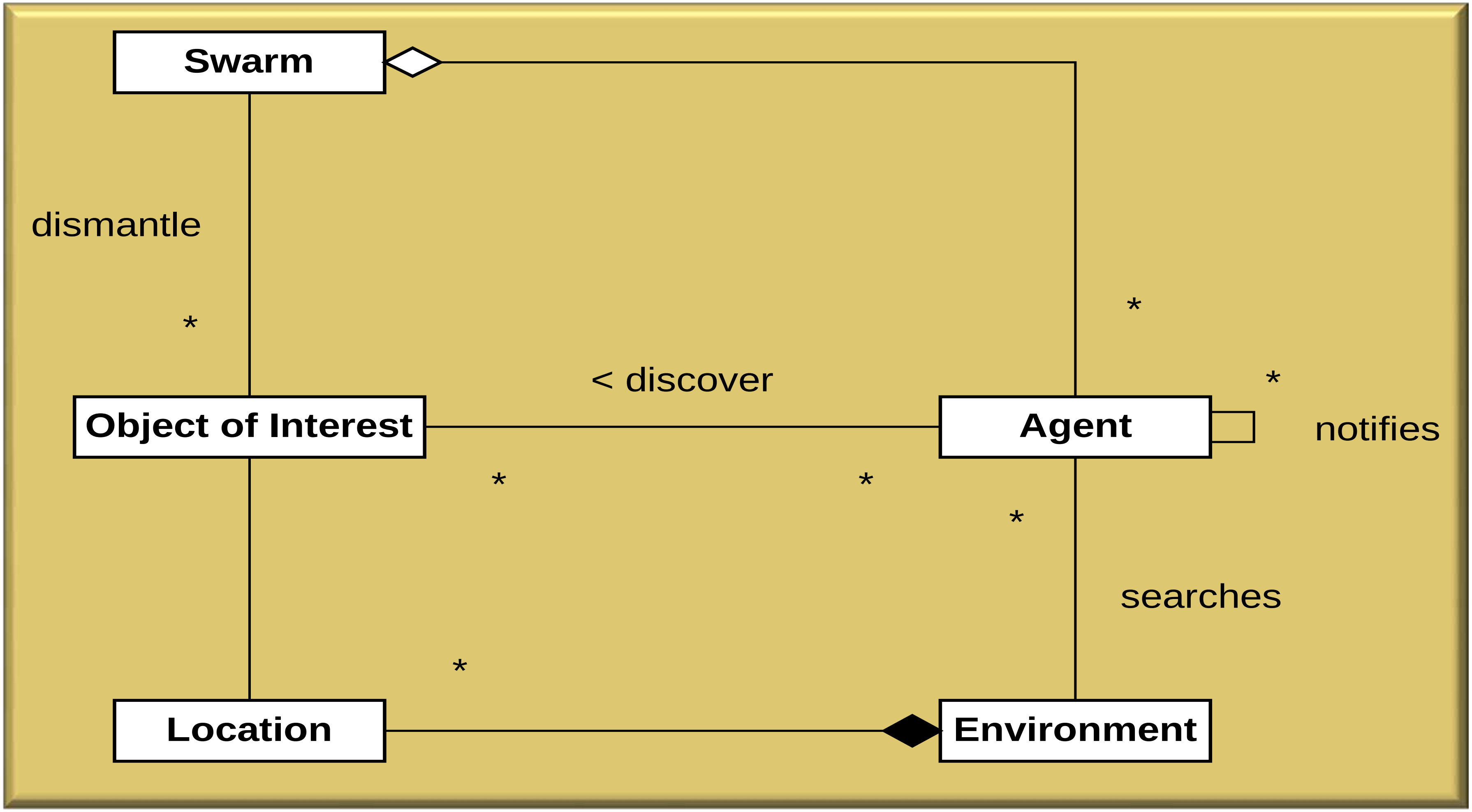
SDC Static Structure



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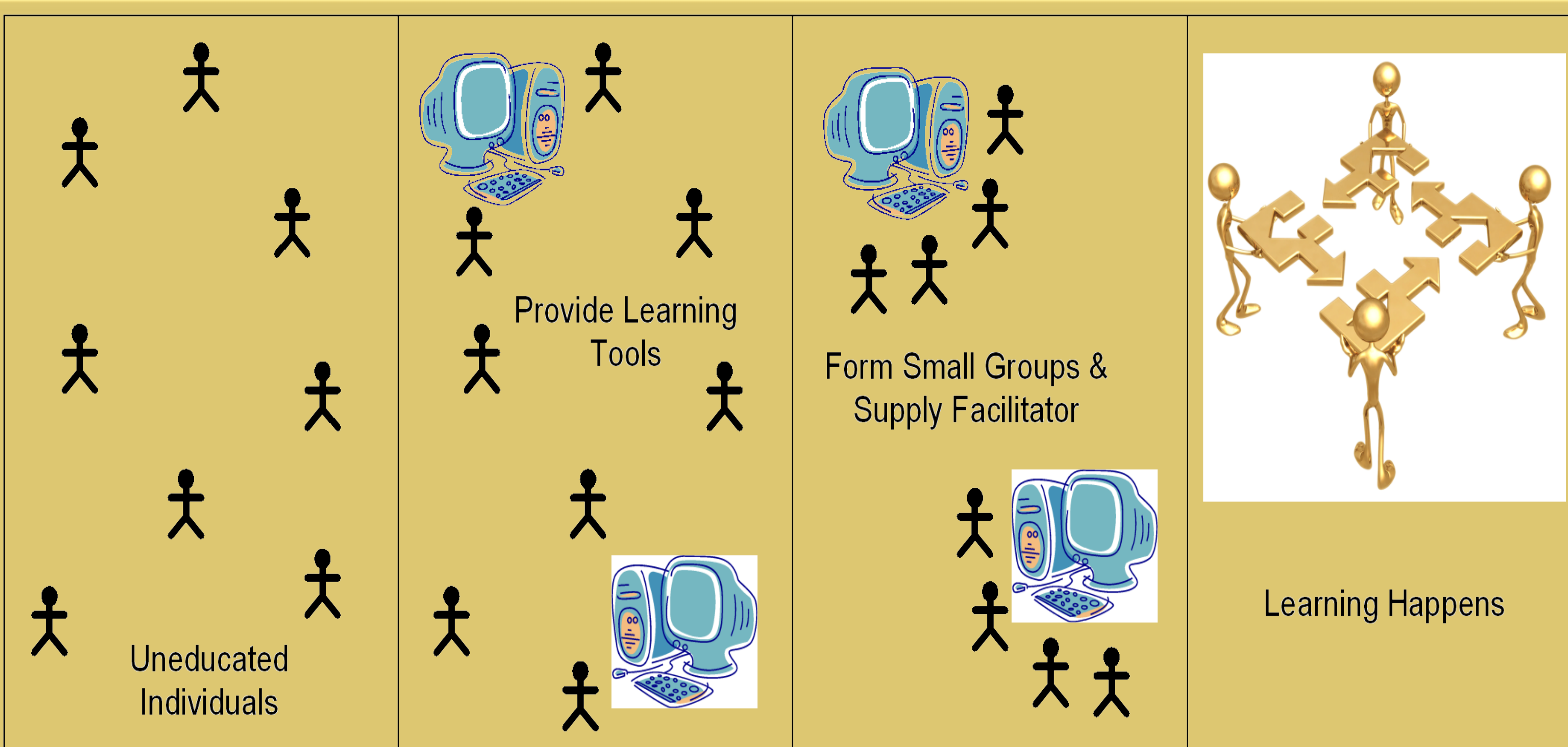
Collaborative Learning



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Name	Collaborative Learning
Context	A group of individuals, potentially uneducated, need to learn a new topic. They need to be motivated to overcome perceived hindrances. They have access to fundamental tools (e.g. computer and Internet) to complete the objective.
Problem	A group of individuals are tasked, or take initiative, to learn a specific topic without explicit educational instruction.
Forces	• Peer collaboration in conflict with peer competition. • Natural human learning curiosity vs. availability of learning objectives and situational exposure. • Teacher expertise vs. shortage of teachers.
Solution	Small teams (3-4) with a common learning interest obtain, or are given, access to necessary tools (e.g., Internet search). Mediators may be accessible to assist and answer questions, though not necessarily expert on the topic.
Examples	• SOLE • Hole in The Wall • Teaching methods

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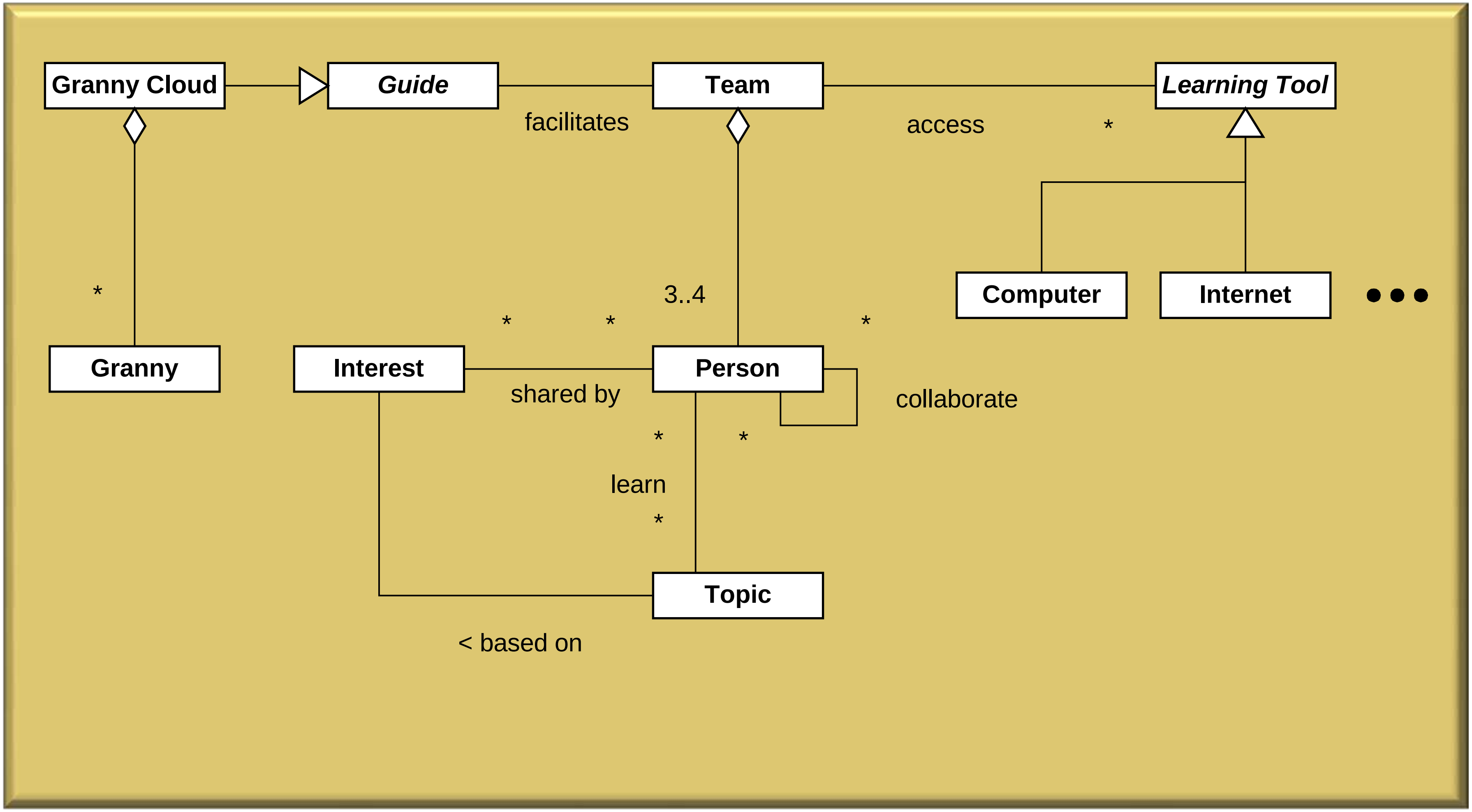
CL Static Structure



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Summary

- Six necessary characteristics for self-organization:
  common purpose, conditional dependency, situation awareness, adaptability, autonomy, whole-part relationship
- Candidate patterns:
  - *Crowd sourced incident reporting*
  - *Swarm discovery and cooperation*
  - *Collaborative learning*

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Next Steps

- Delve deeper into each pattern and provide detailed analysis and additional examples
- Map patterns to contemporary problems; apply theory to the real world
- Identify and document additional self-organizing patterns

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Q&A

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Acronyms

Acronym	Definition
CSIR	Crowd Source Incident Reporting
DoD	Department of Defense
LRR	Long Range Recruitment
Q&A	Questions & Answers
SDC	Swarming Discovery & Cooperation
SE	Systems Engineering
SO	Self Organizing
SOLE	Self-organized Learning Environment
SoS	System of Systems
SRR	Short Range Recruitment

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