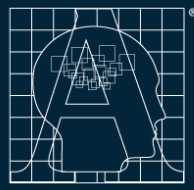

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Empirically-driven Analysis for Model-driven Experimentation: From Lab to Sea and Back Again (Part 2)

Yuri Levchuk, Ph.D., Aptima Inc.
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Daniel Serfaty., Aptima Inc.

CCRTS, 2006

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Agenda

- ESG Opportunity for A2C2 Program: Blending Science with Operations
- Diagnosis of ESG Organization
- Findings While On-board an ESG Flagship
- Organization-Mission Rhythm Model
- Model-driven Experimental Design

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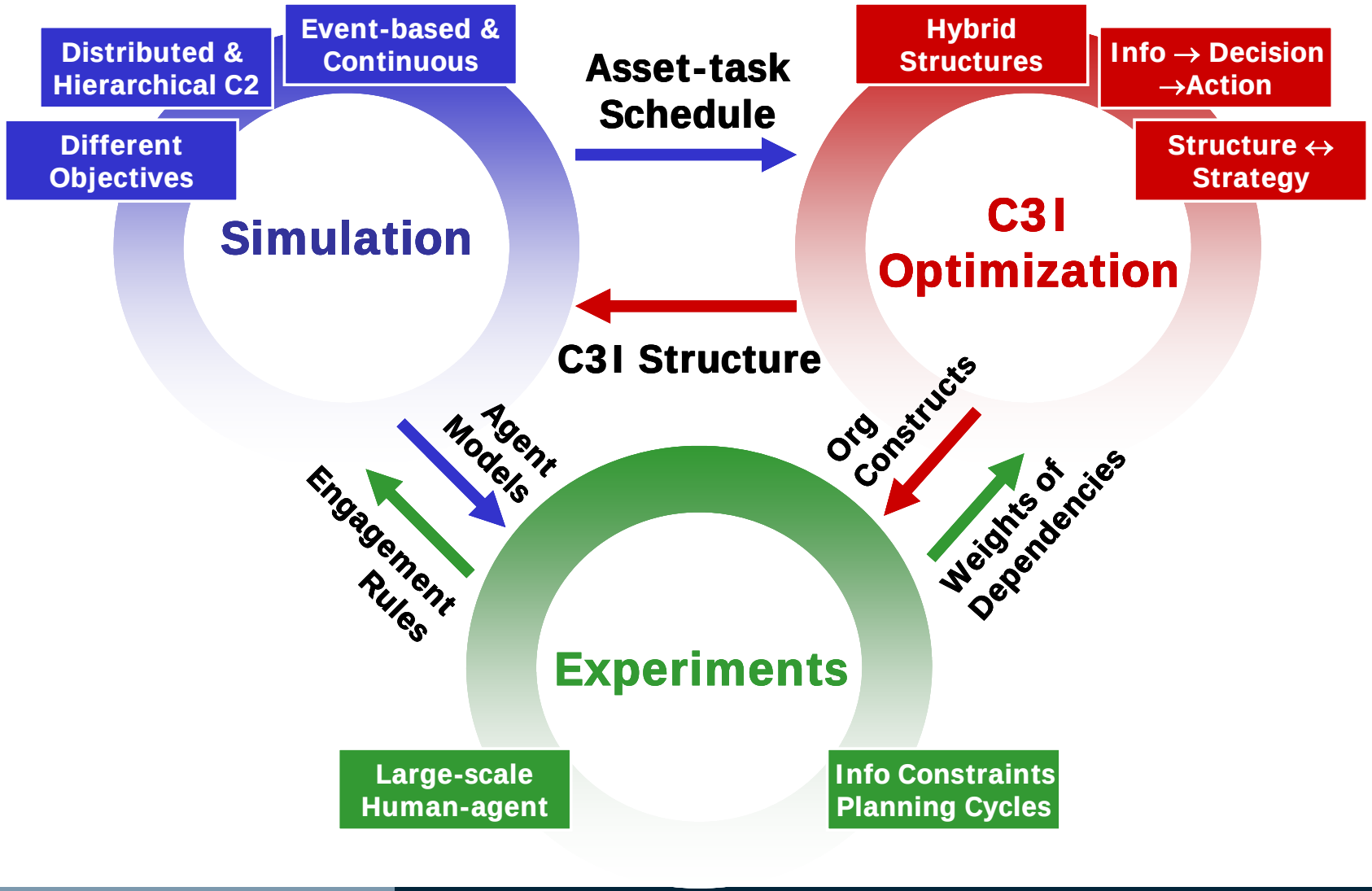
A2C2 modeling and experimentation framework



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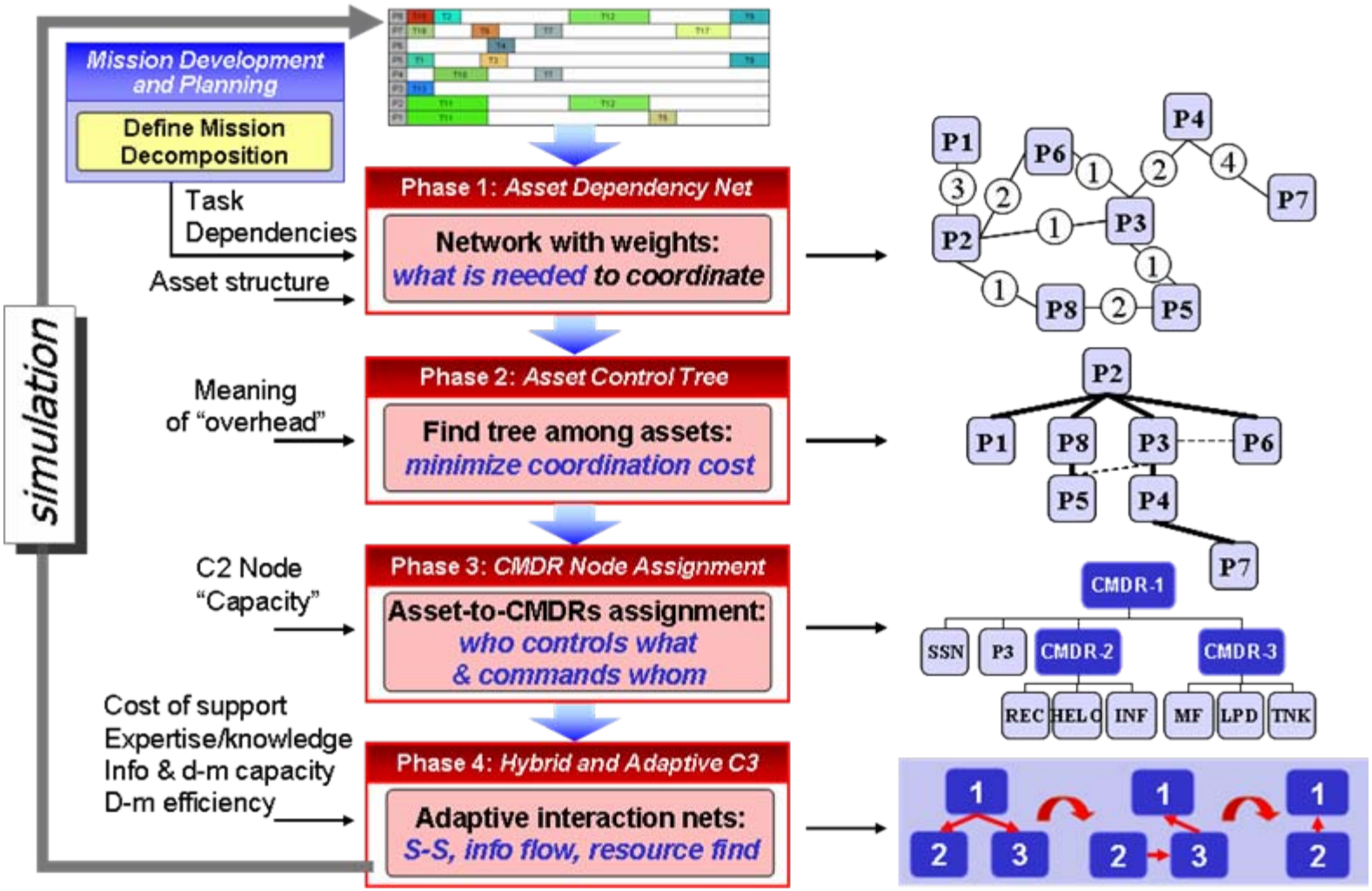
Optimization Methodology: Overview

Model paradigm: Event-driven distributed mission task processing by a hierarchical C2 organization



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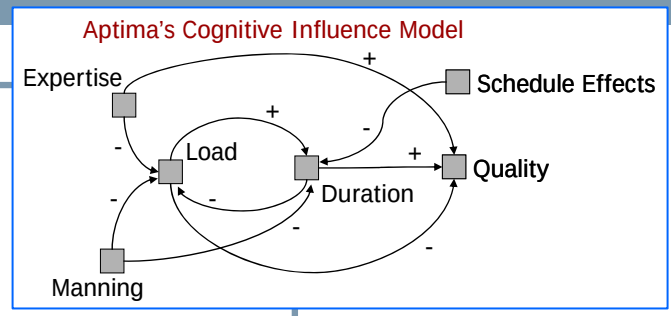
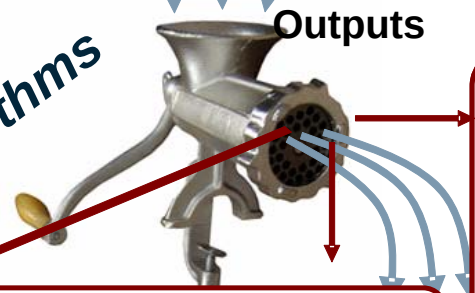
Organizational Engineering



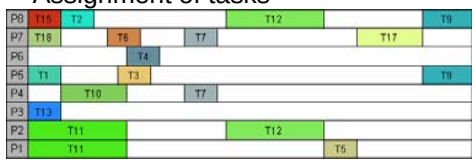
models of resources/technologies, individual cognition, & team interaction

mission environment & objectives

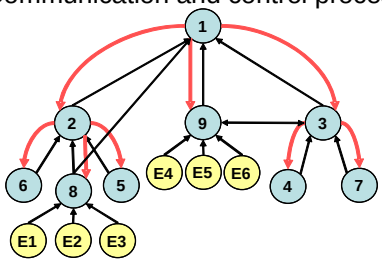
mathematical formalism of organizational theory



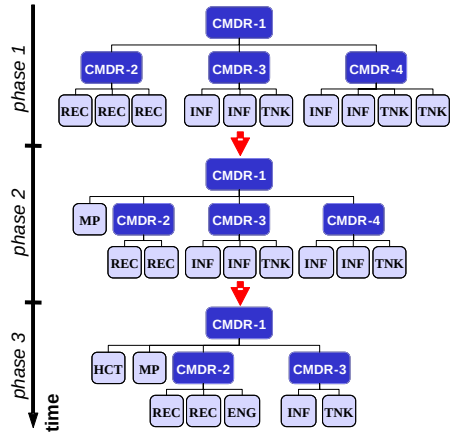
Optimal Mission Execution
- Utilization of agents and resources
- Assignment of tasks



- Communication and control processes



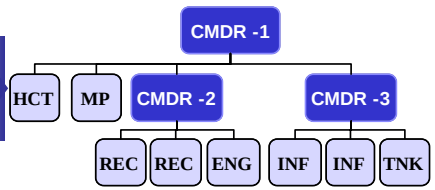
- Structure adaptation



Forces Composition
- Mix of agents to employ

HCT MP ENG
REC REC INF TNK

Optimal Organization
- Assignment of resources to agents
- Command hierarchy



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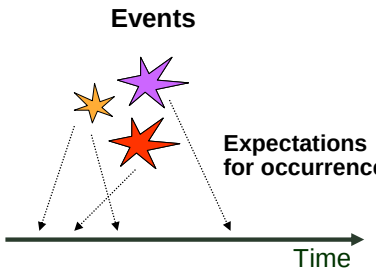
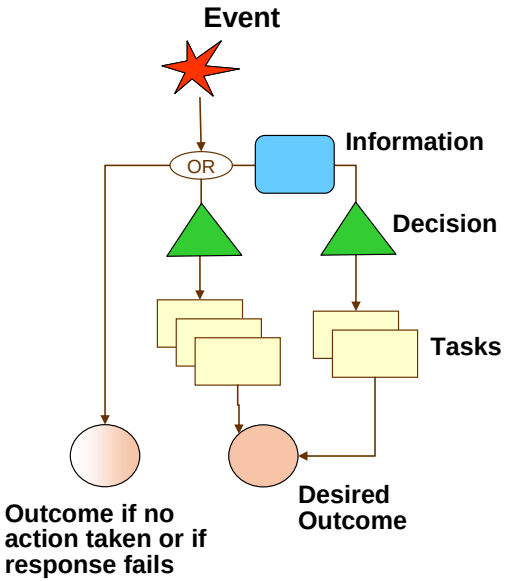
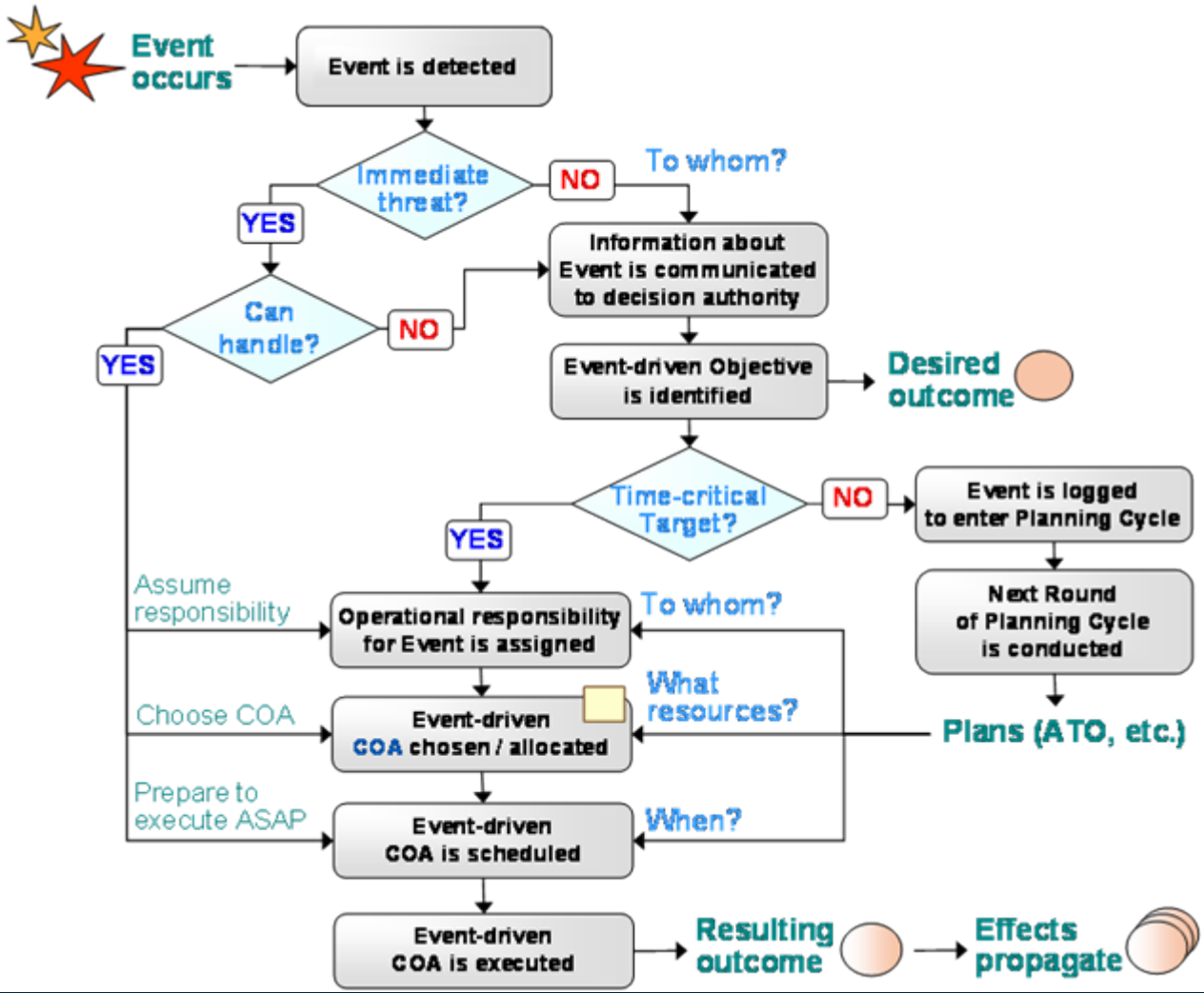
Simulation Methodology: Overview

Model paradigm: Event-driven distributed mission task processing by a hierarchical C2 organization







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A2C2 Scientific Approach: Model-Based Experimentation

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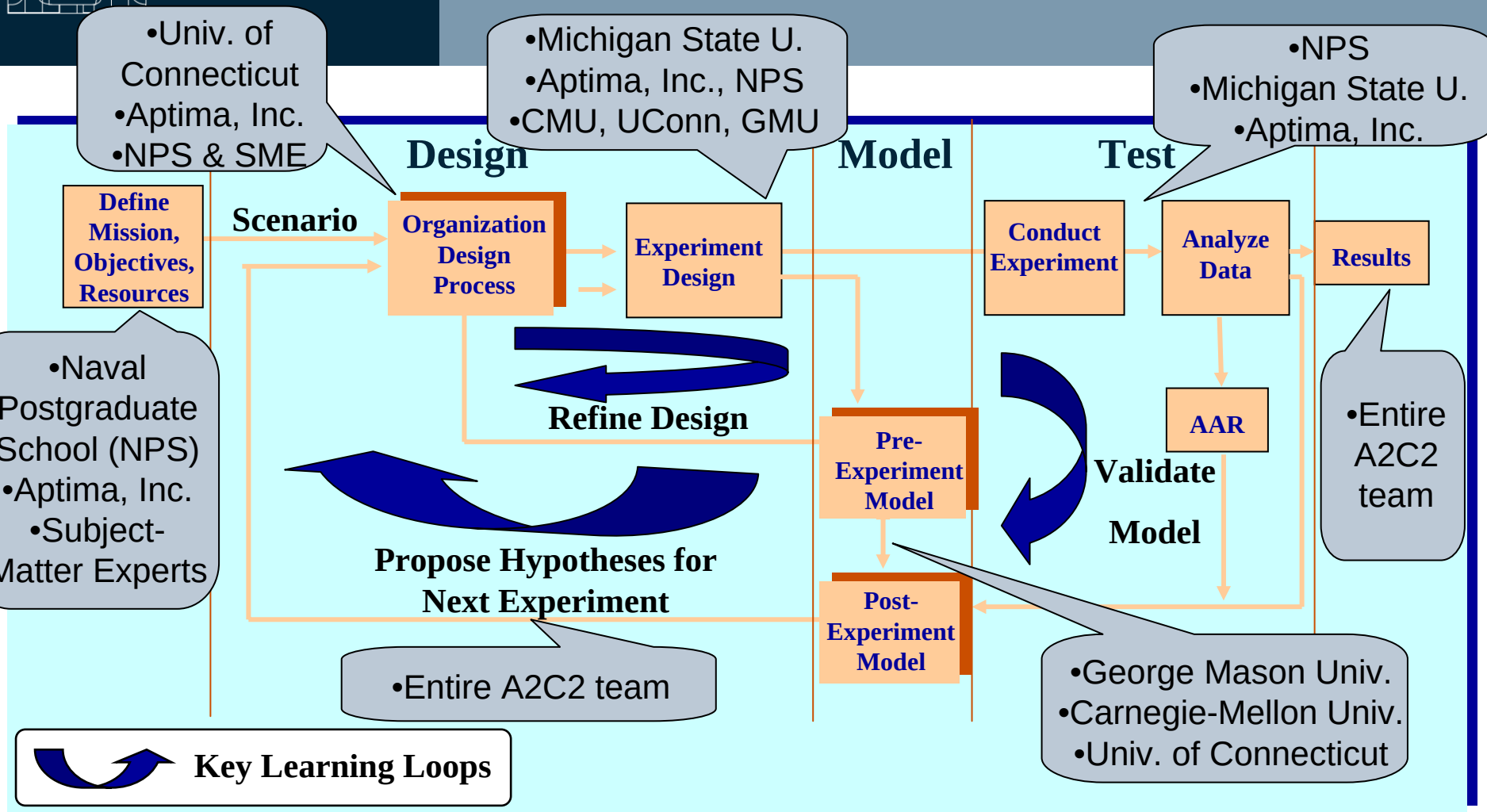

- Integration of Modeling, Simulation, and Experiments
- Have performed 10 Design-Model-Test-Model cycles to date

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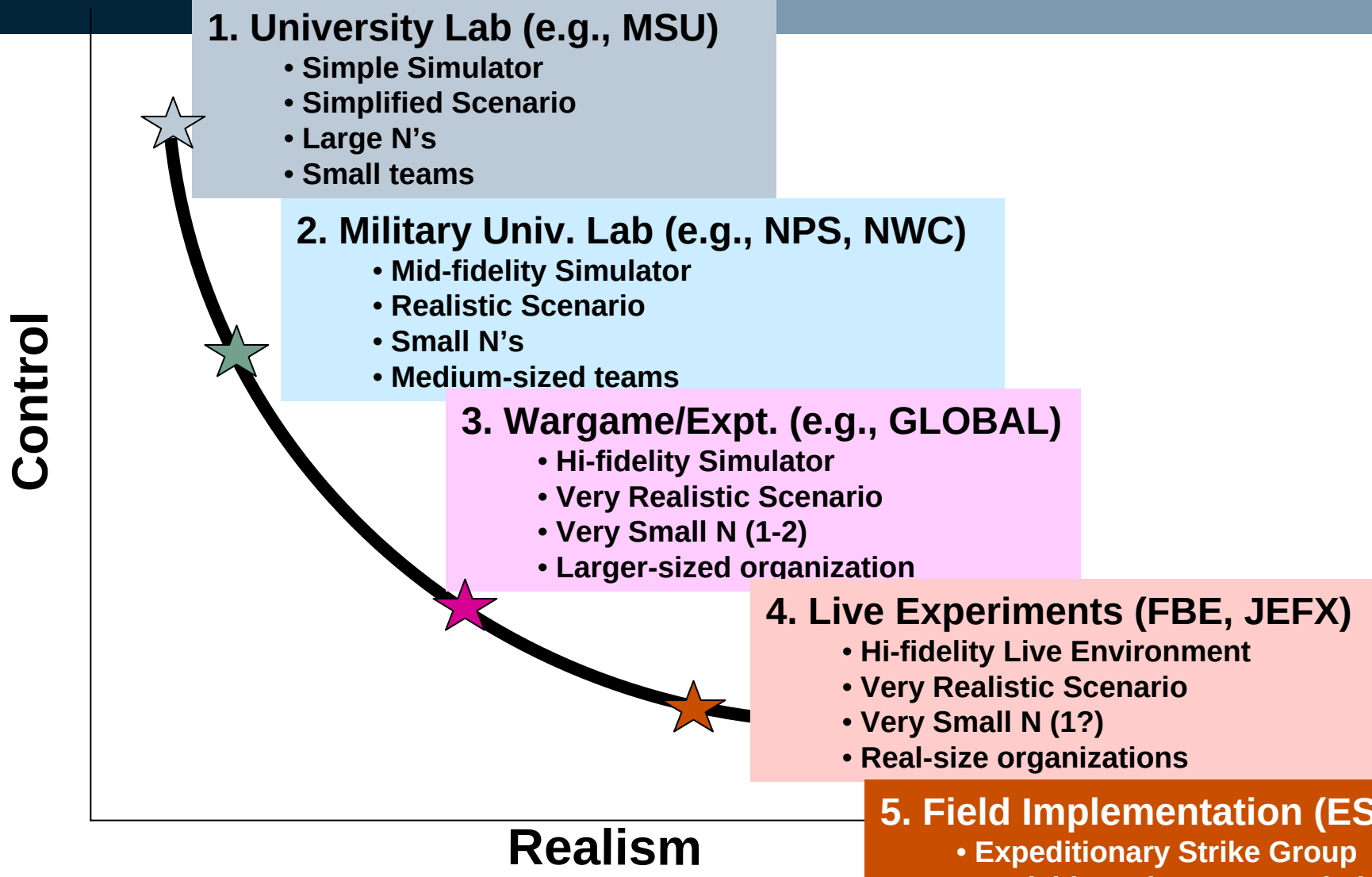
Fundamental Experimentation Trade-Off



1. University Lab (e.g., MSU)
- Simple Simulator
- Simplified Scenario
- Large N's
- Small teams

2. Military Univ. Lab (e.g., NPS, NWC)
- Mid-fidelity Simulator
- Realistic Scenario
- Small N's
- Medium-sized teams

3. Wargame/Expt. (e.g., GLOBAL)
- Hi-fidelity Simulator
- Very Realistic Scenario
- Very Small N (1-2)
- Larger-sized organization

4. Live Experiments (FBE, JEFX)
- Hi-fidelity Live Environment
- Very Realistic Scenario
- Very Small N (1?)
- Real-size organizations

5. Field Implementation (ESG)
- Expeditionary Strike Group
- Model-based recommendations for Organizational Diagnosis & Design

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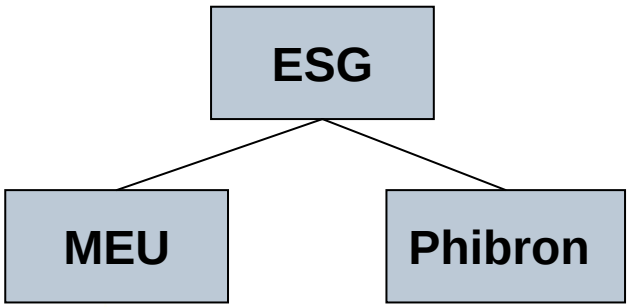
ESG Mission Elements



ESG Force Composition (Assets and their Capabilities)

Elements of ESG Missions

Fire support of land operations

Anti-air warfare

From humanitarian aid to major theater war

Embark, transport, land

Sea surface etc. combat

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Findings While On-board an ESG Flagship

- Three internal organizational dynamics rhythms – for MEU, PHIBRON, and ESG
- Example observations and data collected:
  - event-driven sequences of operational activities
  - mission requirements from *objectives* to *goal-sub-goal chains*
  - example ESG C2 arrangements - how they work in practice
  - performance tradeoffs
  - areas of responsibility of ESG commanders, key “management decisions” and critical events that spawn these decisions
  - assimilated use of multi-capable ISR platforms (UAV, E2C, P3, etc.)
  - *information flows* in network-enabled ESG C2 systems
- Supporting-Supported Relationships – not stressed

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Critical ESG Issues Diagnosed

- Structure and (Re)configurability of the PHIBRON cell
  - Impact of multiple doctrines on the PHIBRON operations and processes
- ISR commander/coordinator
- Hybrid Supporting-Supported Structures

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In the Lab Again: Organization-Mission Rhythm Model

- Goal Roadmap Dimension of the Mission Definition
- Organization-Mission Rhythm Model
- Decision Models and Mission Execution Rhythm

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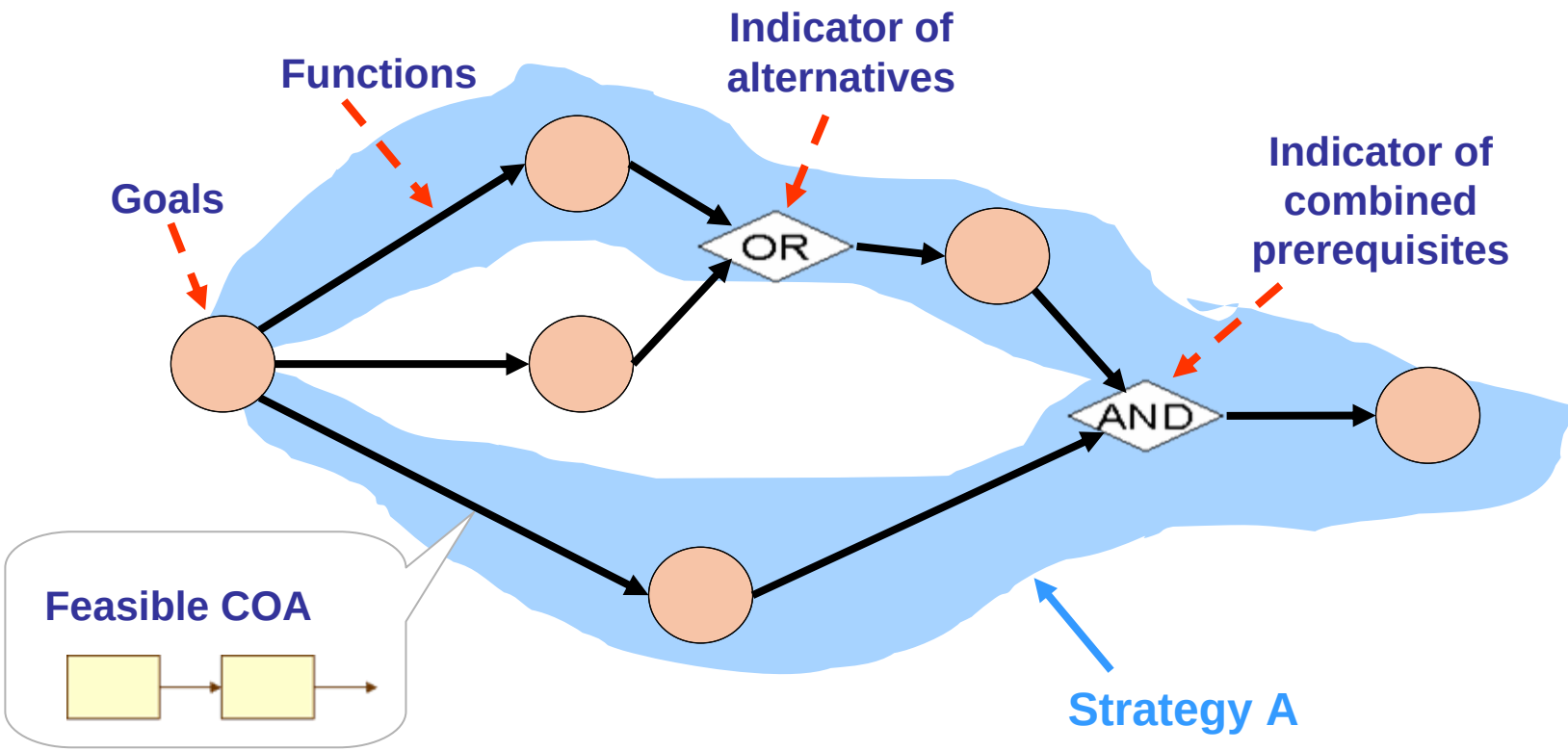
Goal Roadmap Dimension of the Mission Definition



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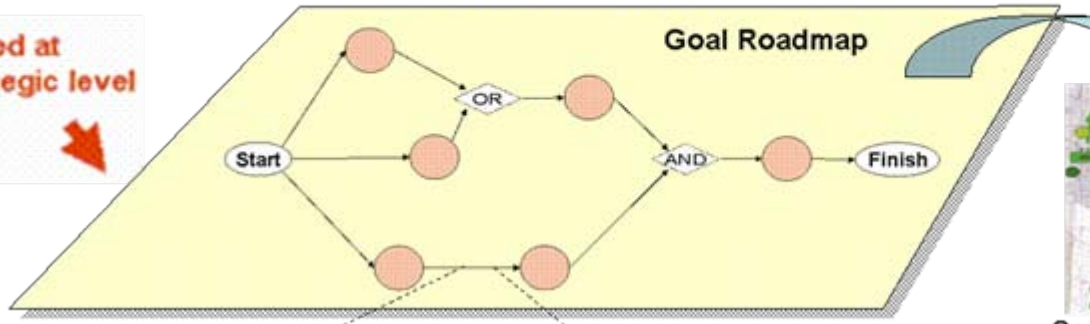
Goal Roadmap Dimension of the Mission Definition

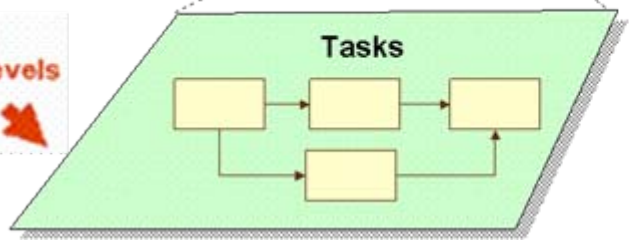
(a) Strategy Roadmap - Goals and **Enabling Relationships:** Functional control over Battlespace and/or Environment

Edited at strategic level



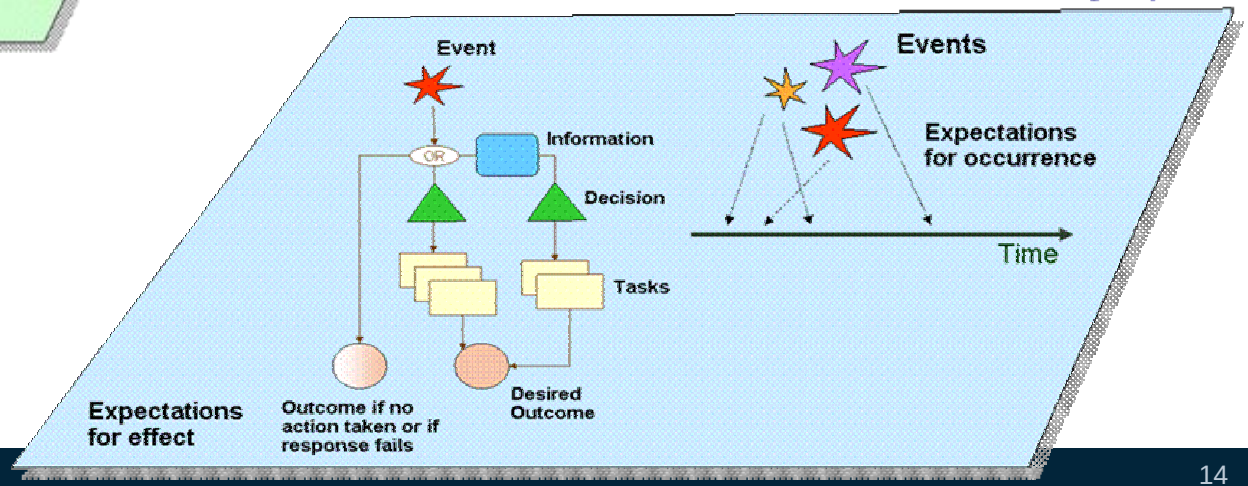
Goals that map to geography

Edited at tactical levels



(b) Mission Task Graph - Courses of Actions based on **Tasks**

(c) Event-driven Decision-Action Policies - Risk Assessment and Contingency Planning



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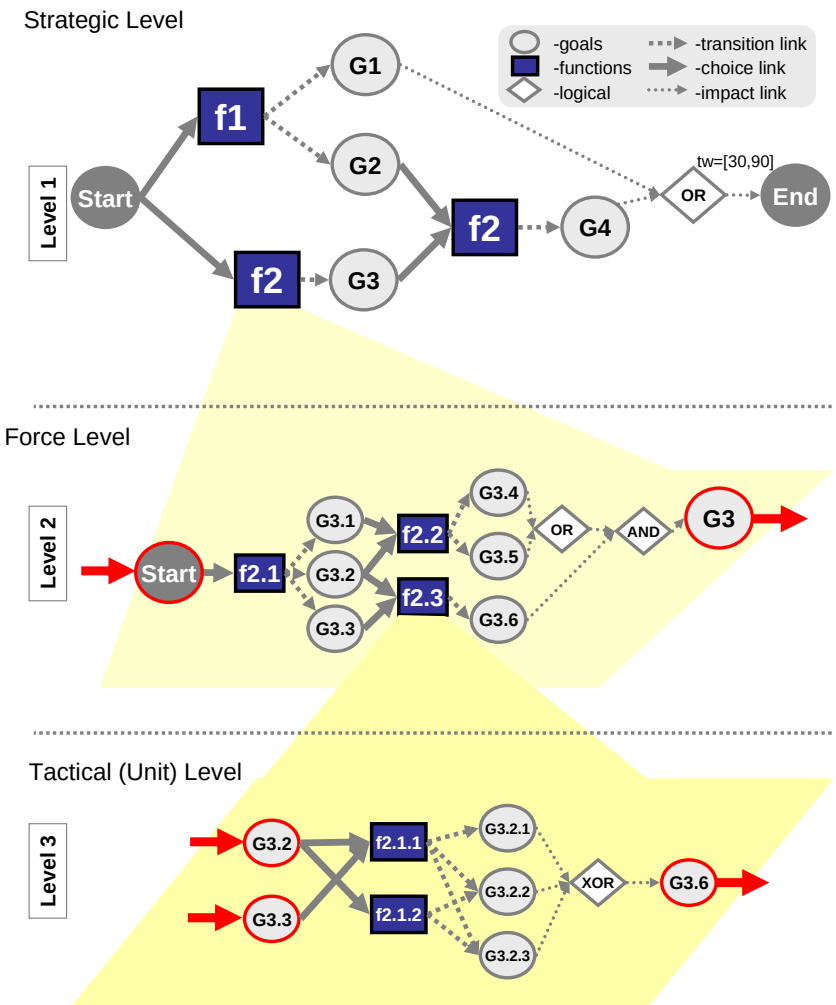
Goal Roadmap Dimension of the Mission Definition



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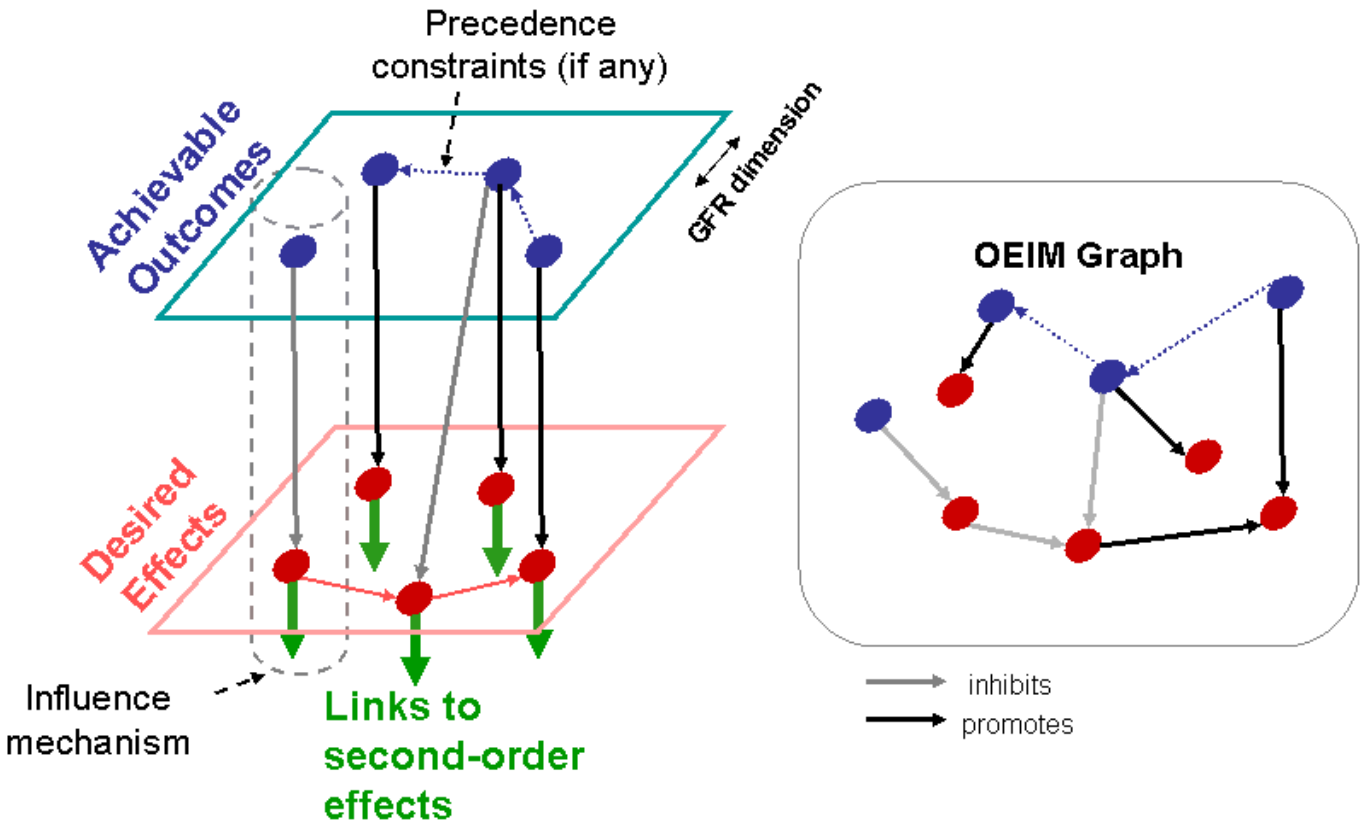
Goal Roadmap Dimension of the Mission Definition



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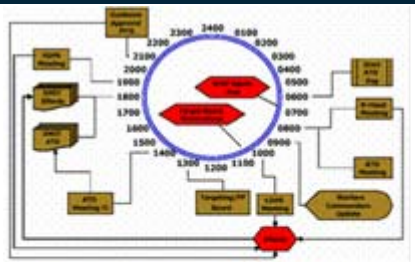
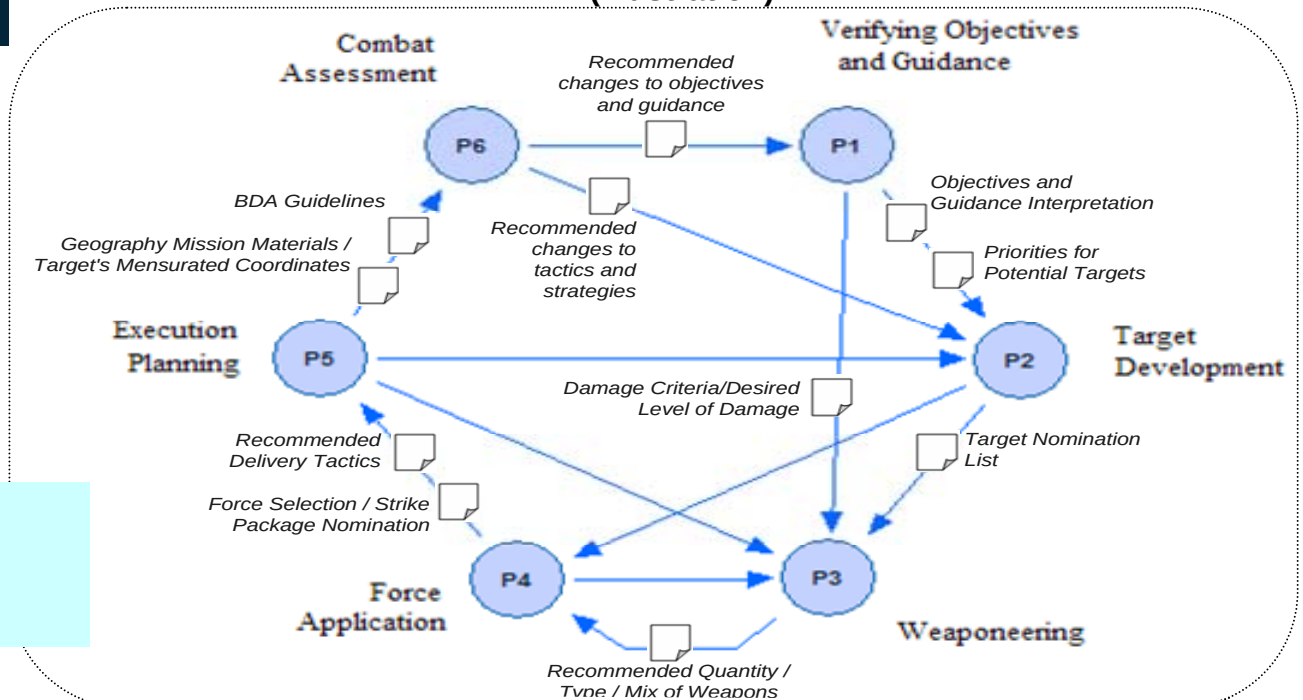
Organizational Process Model

Information Processing Model generalized to include mission execution and effects (illustration)

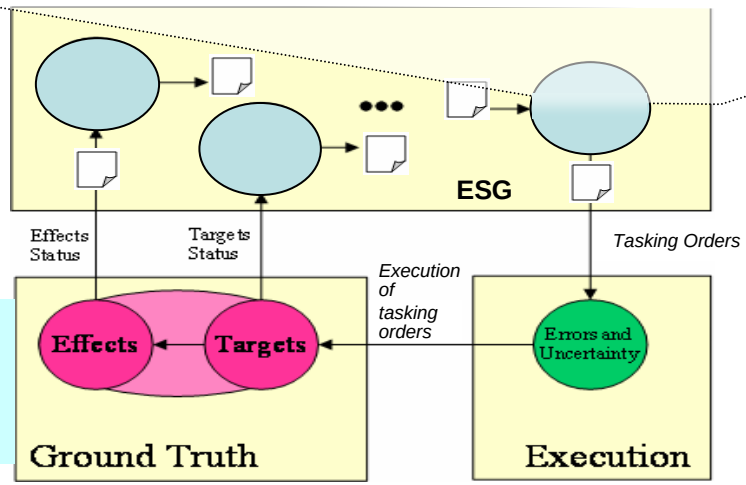


- Need to simulate / measure
  - ESG Battle Rhythm
  - Phibron Battle Rhythm
  - MEU Battle Rhythm



Process Measures:
Timeliness, Completeness, Correctness, and Clarity of information outputs

Measure correlation



Performance Measures:
Effectiveness and Efficiency, % of Objectives achieved, Task Schedule, Resources Lost, etc.

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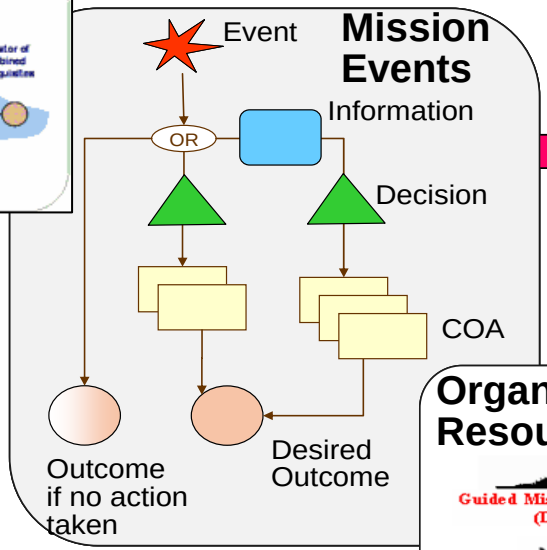
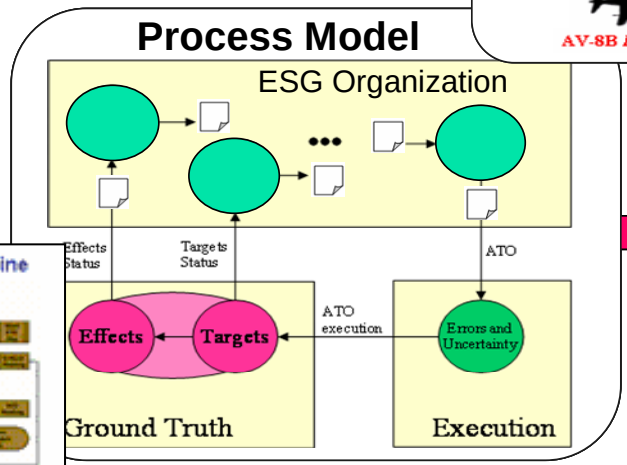
Combining Process-based and Event-based Approaches

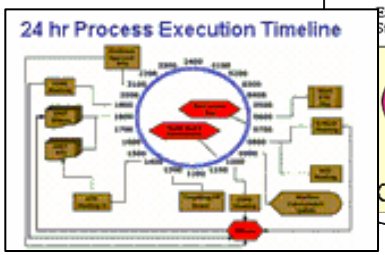


Event-based Simulation & Optimization Executable Model

Process Measures (e.g., Workload, Communications, etc.)

Performance Measures (e.g., Task Schedule, Accuracy, Latencies, etc.)





Process-based Simulation & Assessment Executable Model

Process Measures (e.g., Document/Plans Completeness, Clarity, Correctness, etc.)

Performance Measures (e.g., Effectiveness and Efficiency, Likelihood of success, etc.)

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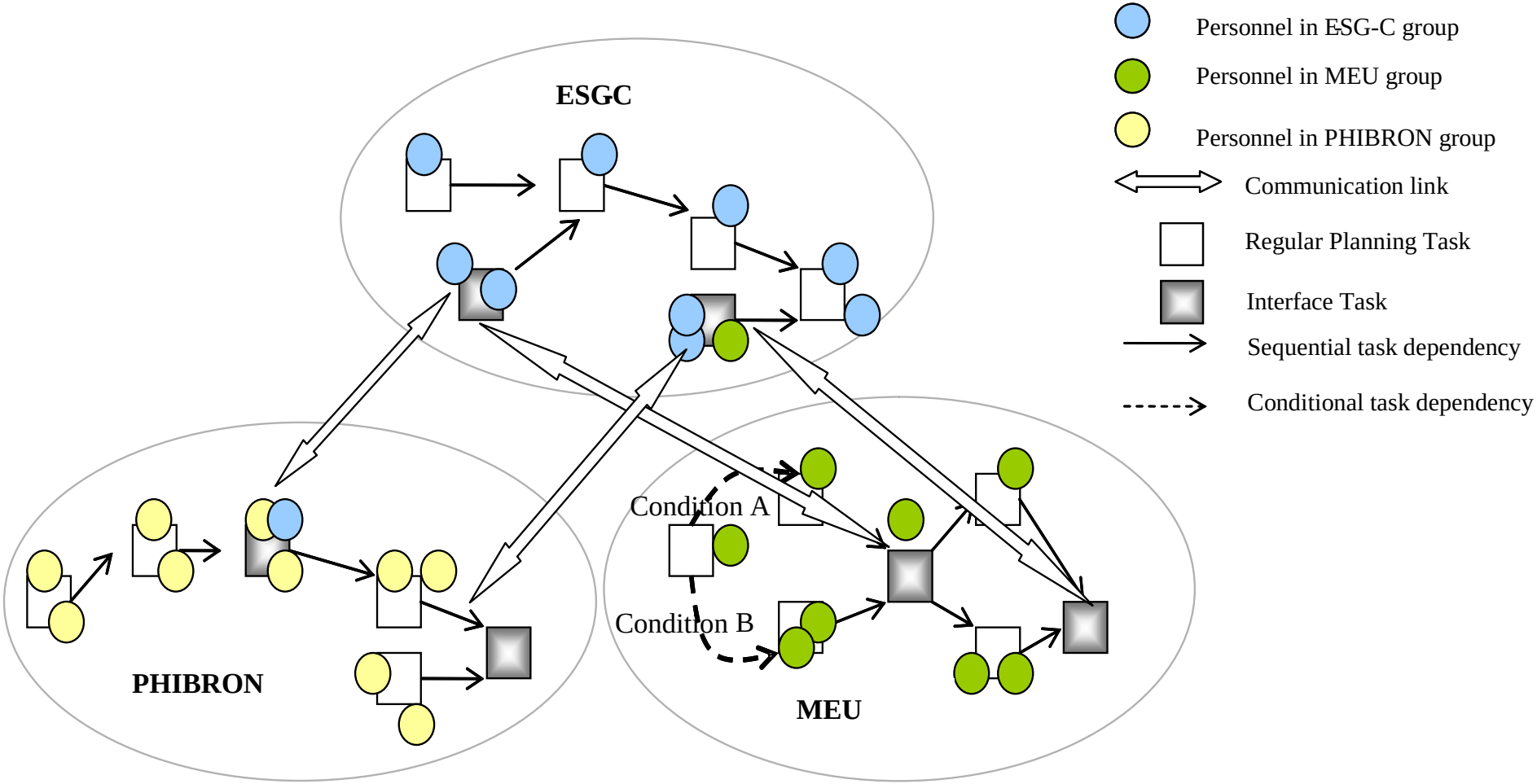
Combining Process-based and Event-based Approaches: Illustration



Time Driven Planning Process

Event Driven Planning Process

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Designing Human-in-the-loop A2C2 Experiments

- Key concepts have been abstracted for maximum generalizability to other similarly modular organizations
- Exploring ways to optimize the interaction between the rhythms of organizational sub-groups

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Experiment 1 Design Objectives

- Examine Unity of Command in ESG
- Study hypothesized causes of tension between MEU and Phibron
- Suggest and validate ways to reduce tension and synchronize performance
- Examine role of the ESG under each setting
- Extend the “congruency” concept to include the alignment (congruency) of objectives

Experiment 1 Hypotheses

- Incongruence (misalignment) between MEU and Phibron’s goals results in tension and inferior performance…
- …[thus resulting in] Asynchronous battle rhythm cycles, more stringent competing demands for assets, less synchronization
- Congruence (alignment) between MEU and Phibron’s goals decreases tension and results in superior performance…
- …[thus resulting in] Asynchronous battle rhythm cycles, more stringent competing demands for assets, less synchronization
- After MEU and Phibron will have enough exposure to “mutually congruent” missions, the tension between them will decrease, regardless of what missions they will face.
- Joint training on the “right” missions can improve alignment of goals

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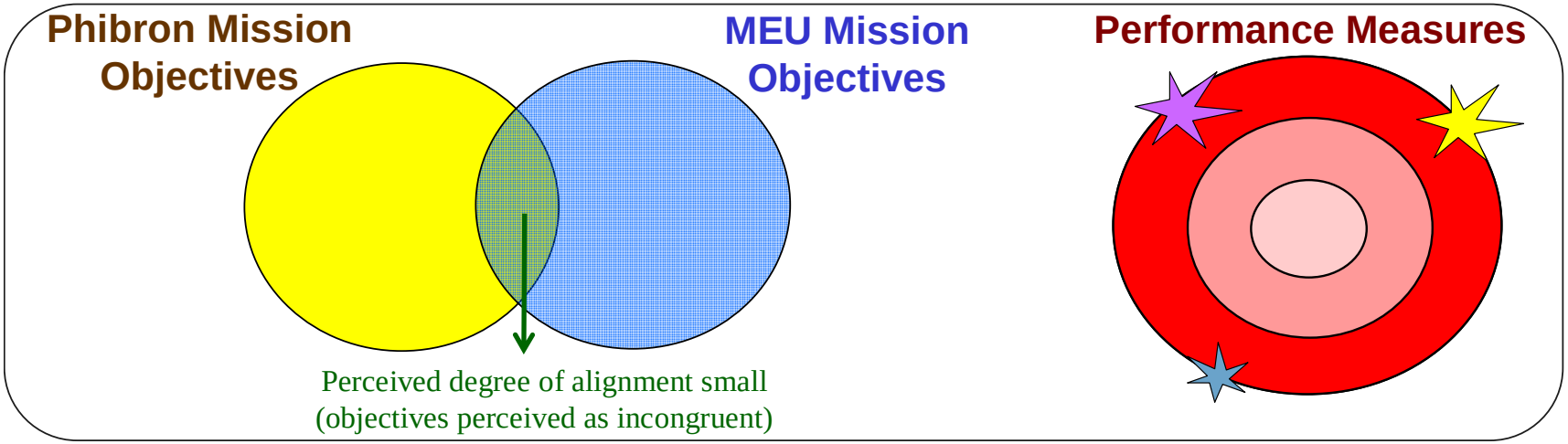
Designing Human-in-the-loop A2C2 Experiments: Illustration



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Designing Human-in-the-loop A2C2 Experiments: Illustration

Scenario 1 – Goals are decoupled

Scenario 1 summary:

The mission for ESG is to protect the oil platforms in the Northern Arabian Gulf (NAG). At the same time, the friendly plane has made an emergency landing in hostile territory controlled by insurgents. The pilot, having been captured, is being held hostage. Two companies of Marines are planning to land to conduct a Tactical Recovery of Aircraft and Personnel and to eliminate insurgency targets.

Mission 1

- Protect oil platforms in Northern Arabian Gulf
- Tactical recovery of aircraft and personnel
  - Recover pilot
  - Destroy enemy's command center (and other enemy's targets)
  - Discover plane (and recover/destroy specific materials/equipment)

Scenario 2 – Goals are aligned (coupled)

Scenario 2 summary:

The ESG Navy and Marines Corps are tasked with conducting multiple visit, board, search and seizure (VBSS) and Maritime Interdiction Operations (MIO) of local shipping traffic, in the Arabian Gulf, to intercept illegal goods as part of the Global War on Terror. Some on shore intelligence gathering may be required.

Mission 2

- Identify and seize/destroy pirate ships
- Patrol Arabian Gulf and check merchant ship
  - Visit vessels
  - Board with force
  - Search for trafficking goods
  - Seize vessels transporting illegal goods
- Ambush cargo offload, be prepared for onshore pursuit

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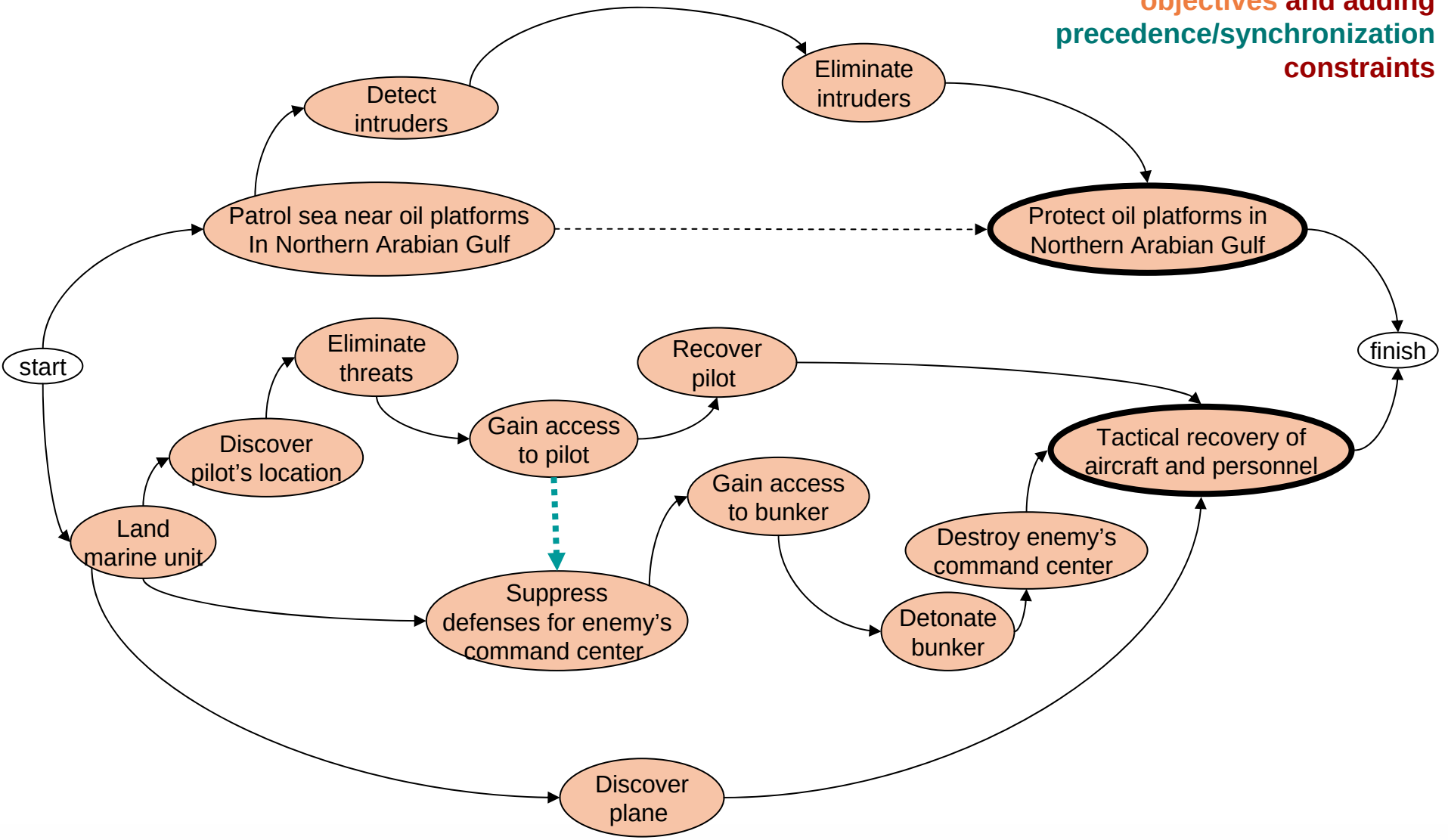
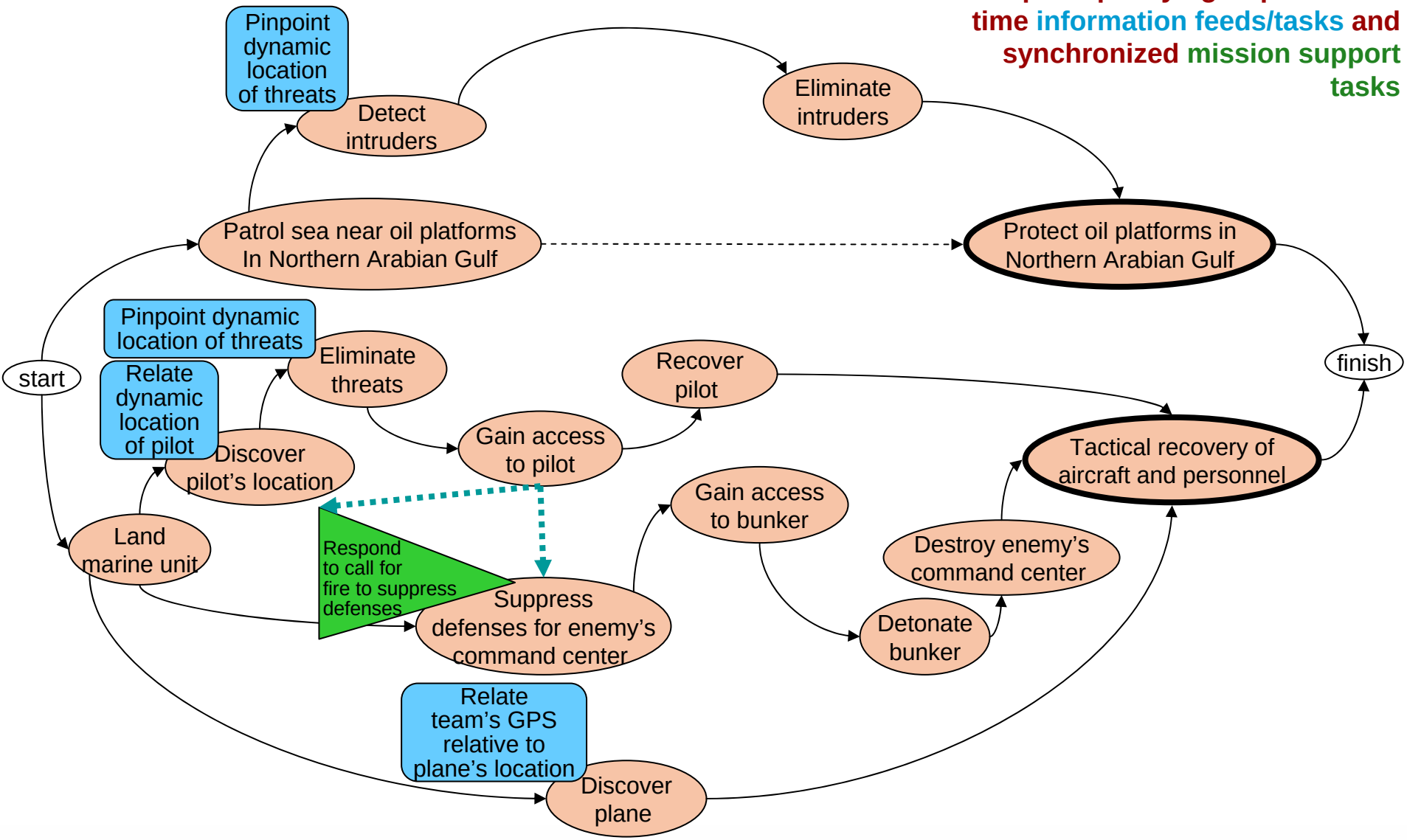
Step 1: Establishing sub-objectives and adding precedence/synchronization constraints

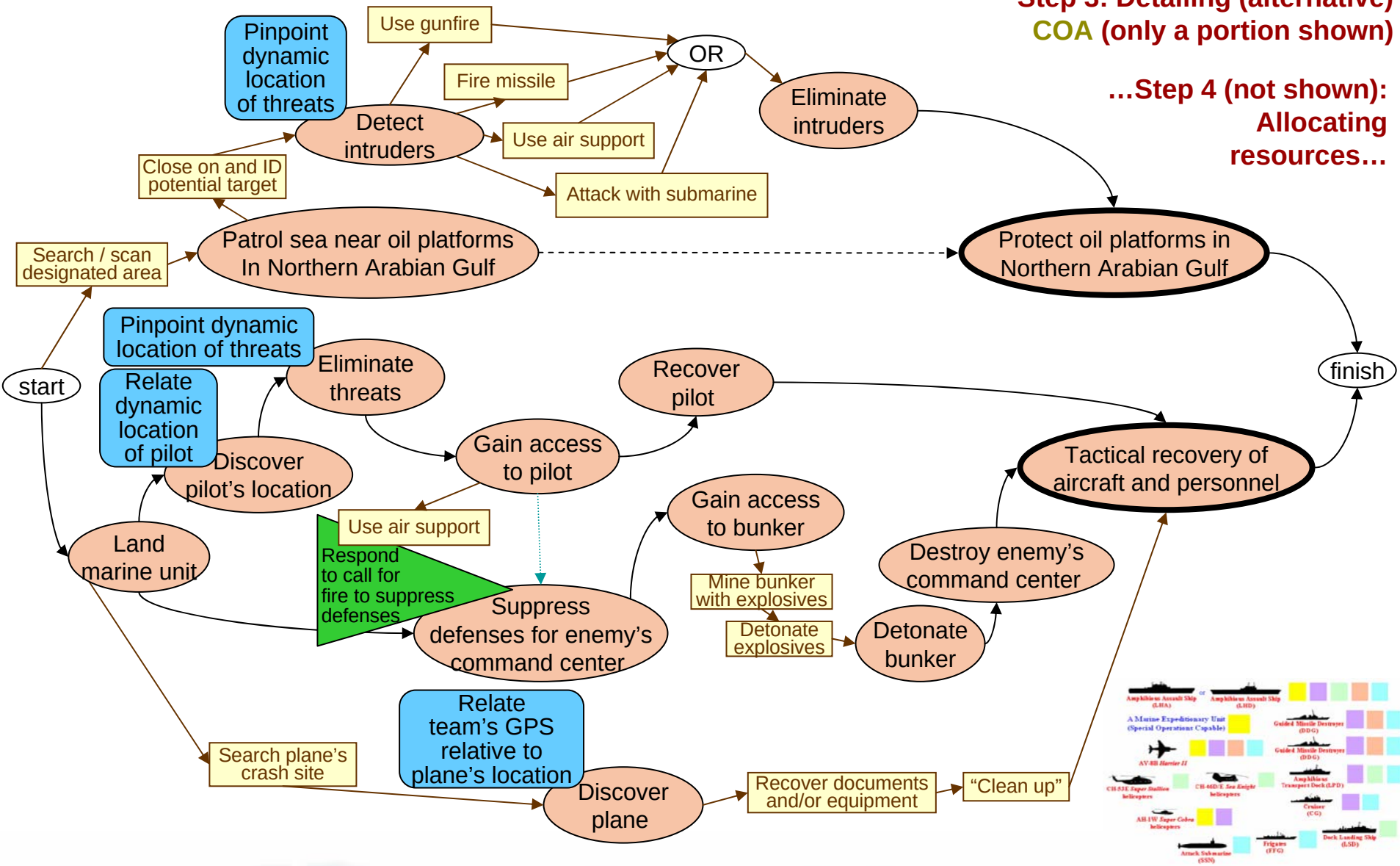


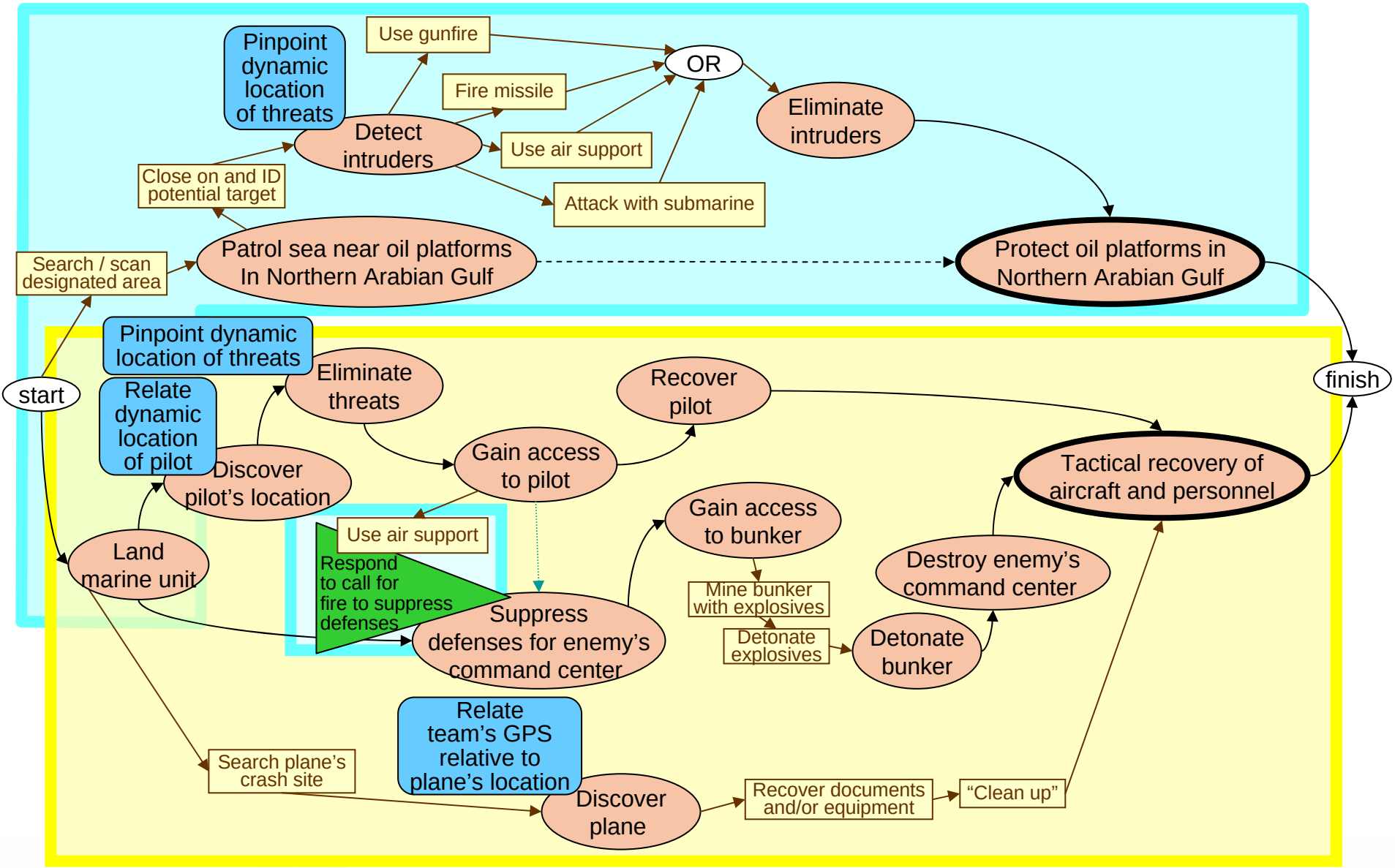
Step 2: Specifying required real-time information feeds/tasks and synchronized mission support tasks



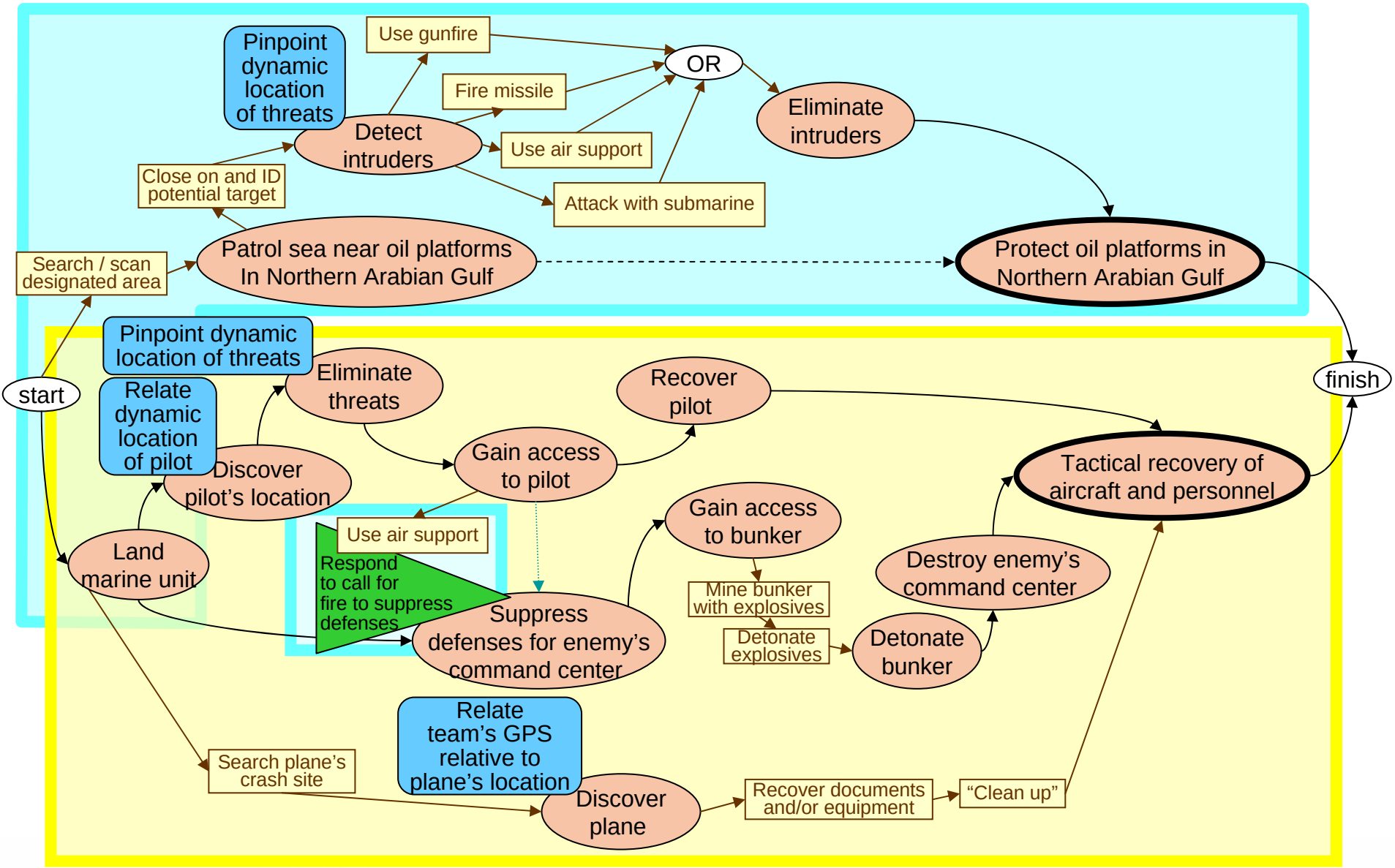
Step 3: Detailing (alternative) COA (only a portion shown)

…Step 4 (not shown): Allocating resources…

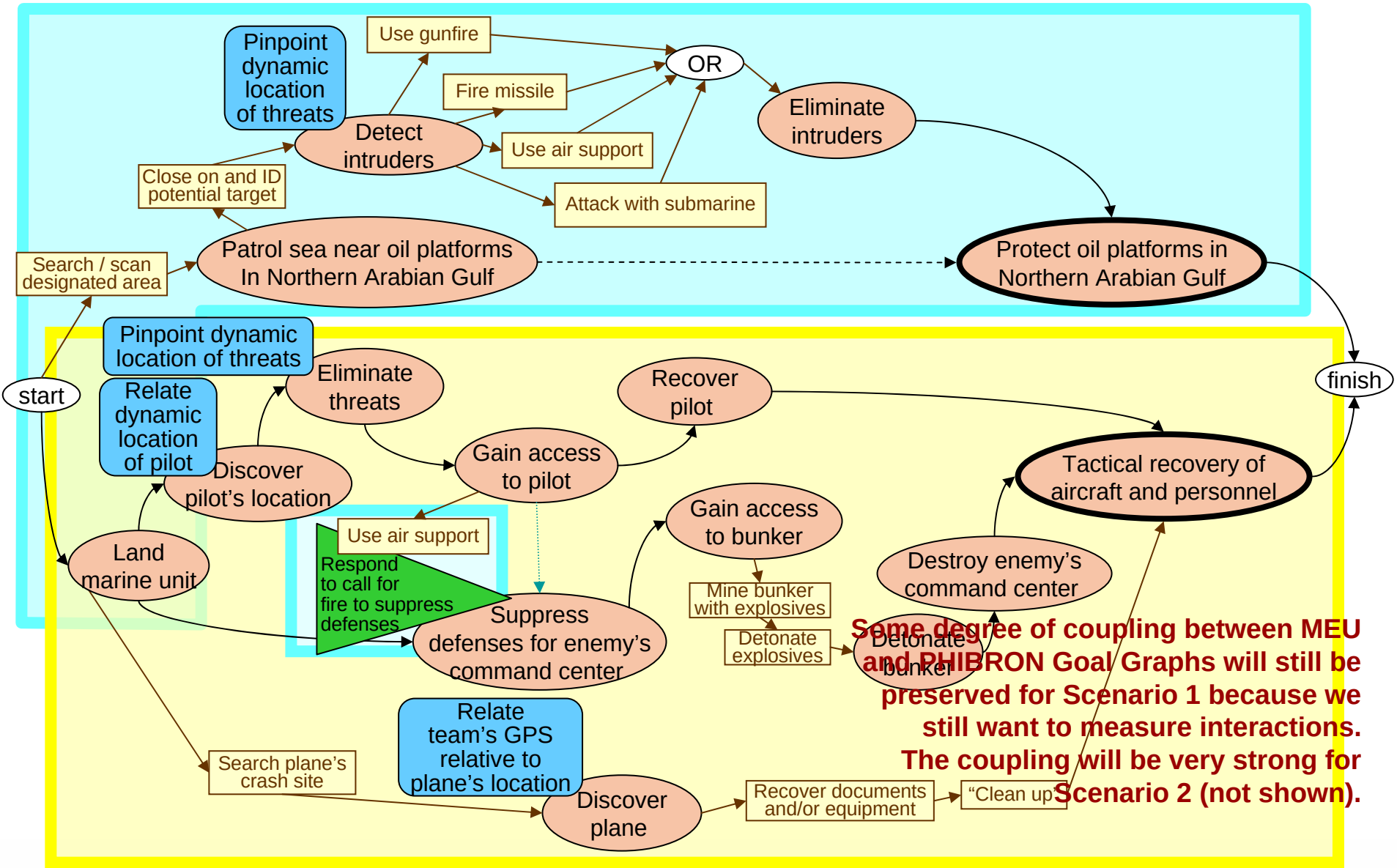




Two loosely coupled "goal graphs"



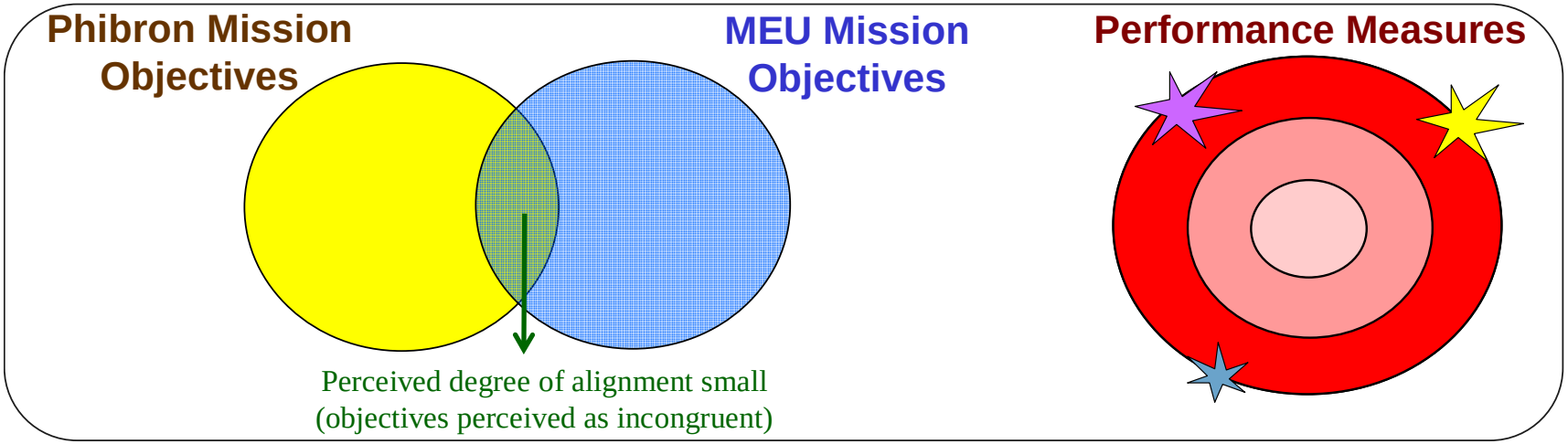
MEU has its own "independent" objectives in sight



Some degree of coupling between MEU and PHIBRON Goal Graphs will still be preserved for Scenario 1 because we still want to measure interactions. The coupling will be very strong for Scenario 2 (not shown).

While PHIBRON also has its own "loosely dependent" objectives in sight

Designing Human-in-the-loop A2C2 Experiments: Illustration



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Experiment 1 Sample Measures

- Unity of Command in ESG
- Degree of Coupling/Alignment between Goal Graphs
- Alignment/Synchronization of ESG/MEU/Phibron's battle rhythm cycles
- Performance accuracy/effectiveness and efficiency
- Communication types and their correlation to information requirements

Experiment 1 Model Predictions

- Scenario 1 will result in asynchronous battle rhythm cycles among ESG, MEU, and Phibron
- Scenario 1 will result in tension between MEU and Phibron and will produce stringent competing demands for assets with less than adequate synchronization
- Scenario 2 will result in synchronized battle rhythm cycles of ESG, MEU, and Phibron
- Scenario 2 will result in lesser tension between MEU and Phibron and will produce lesser competing demands for assets due to adequate synchronization

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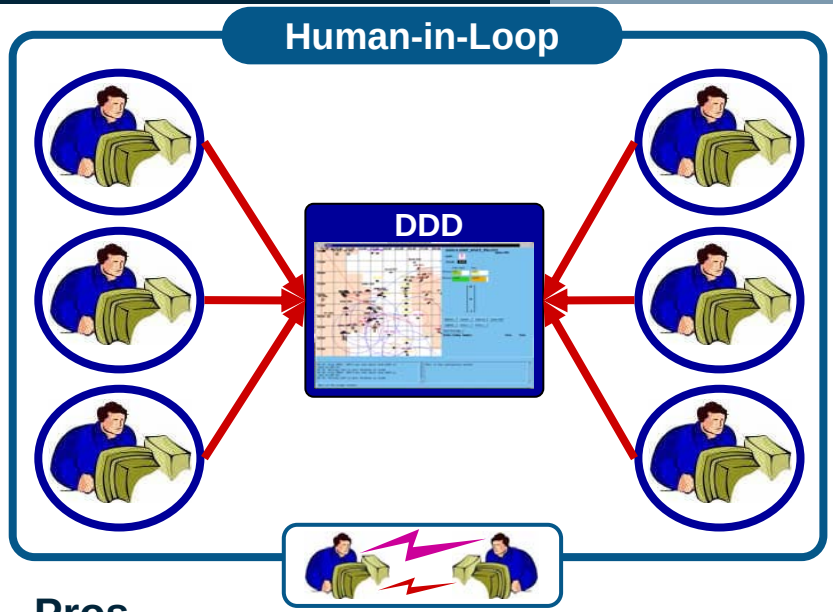
Human-in-loop vs Computational Experiments

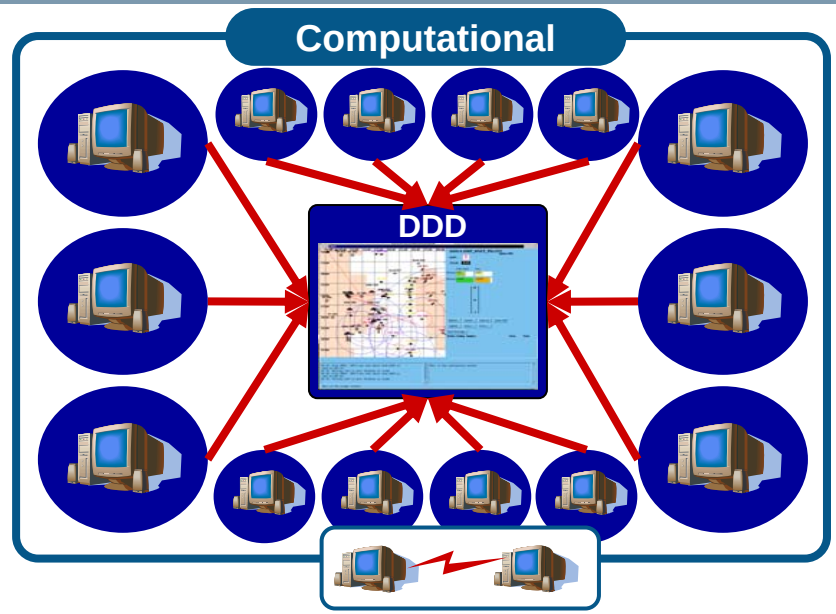


Pros

- Realistic human operator/CMDR behavior on C2 task

Cons

- Limited number of participants
  - Cannot experiment with large-scale organizations
- Limited time & objectives
  - Cannot have enough runs or scenario comparisons



Pros

- Can do large-scale experiments; low cost
- Represent multiple echelons of organization
- Many missions and runs for stat validity

Cons

- Agent **individual behavior** models ≠ humans
  - But can do learning on historic data
- Agent **interactions** ≠ human interactions
  - Cannot use historic data – not recorded
  - Hard to relate to outcome decisions

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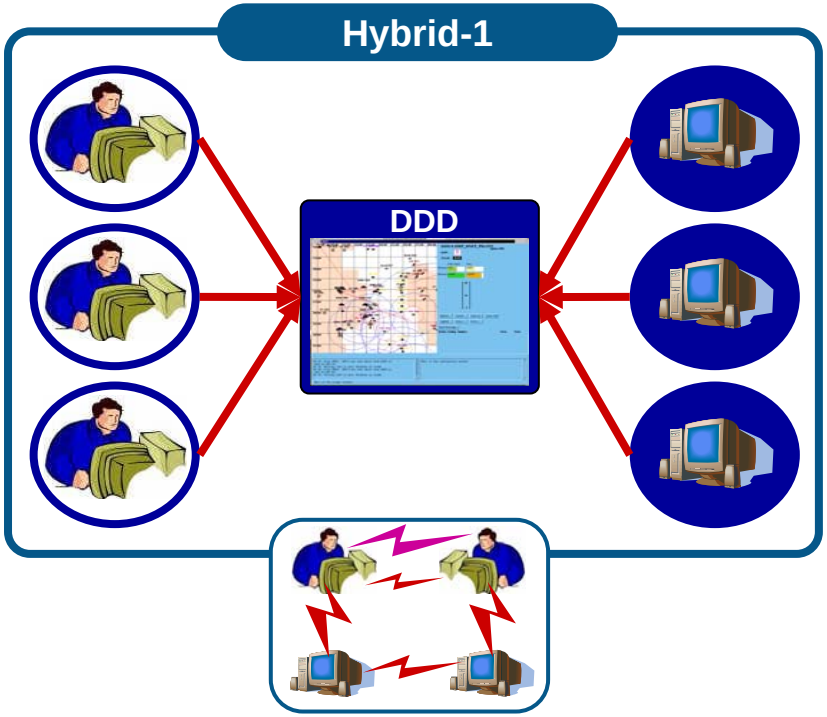
Hybrid Experiment Ideas

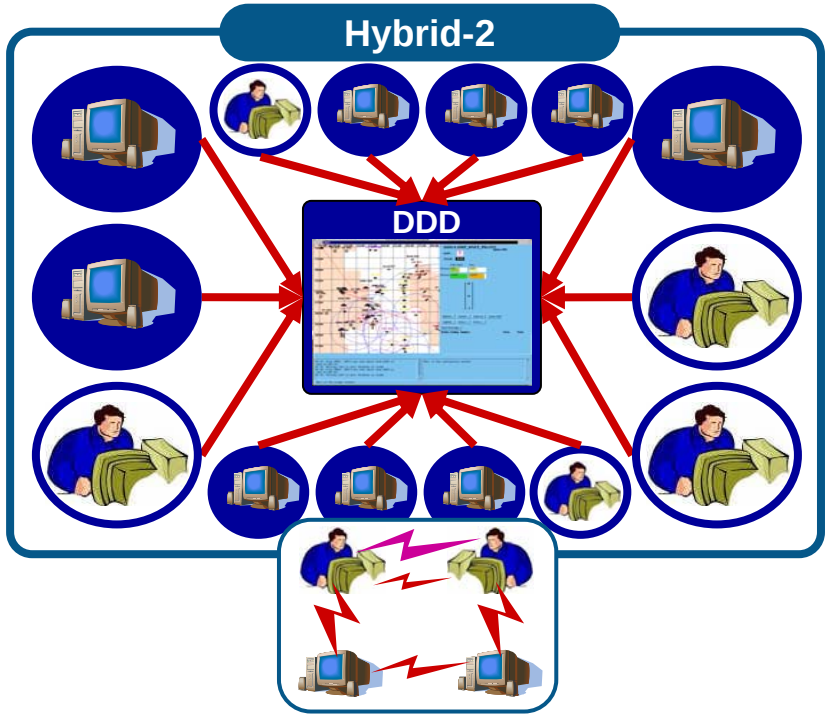


Pros

- Can adapt agents' communication by learning to communicate with humans
- Can compare data to human-in-loop

Cons

- Not large-scale
  - But do not need!



Pros

- Large-scale

Cons

- Cannot make comparisons to HIL
- Do not know how to interpret results

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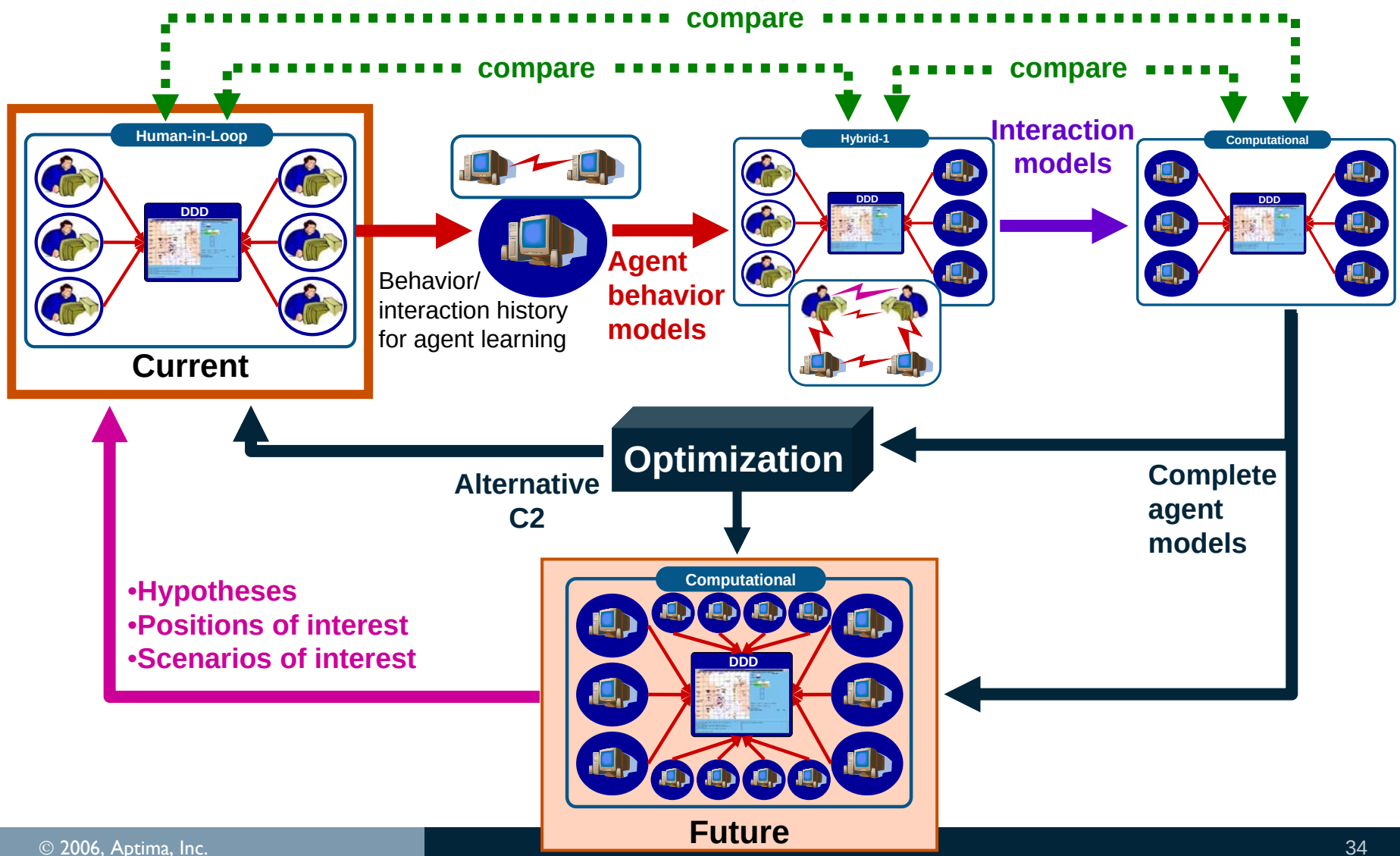
Model-Experiment-Model ConOps



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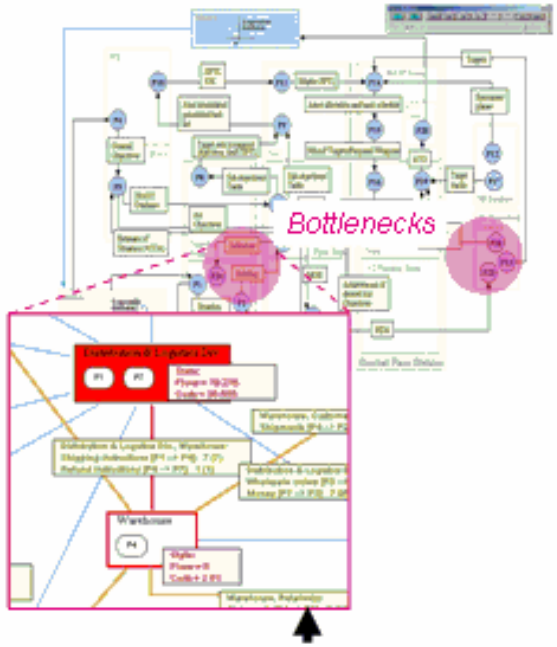
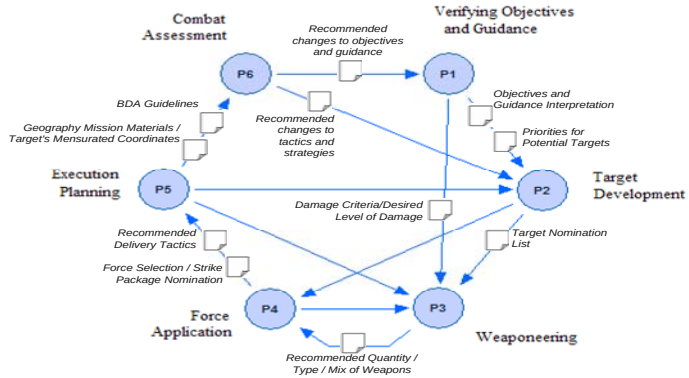
Example Applications

Information Process Model



Receiver bandwidth capacity overloaded, resulting in input queuing, information processing delays, and missed opportunities

Predicting When a Process Becomes the Bottleneck



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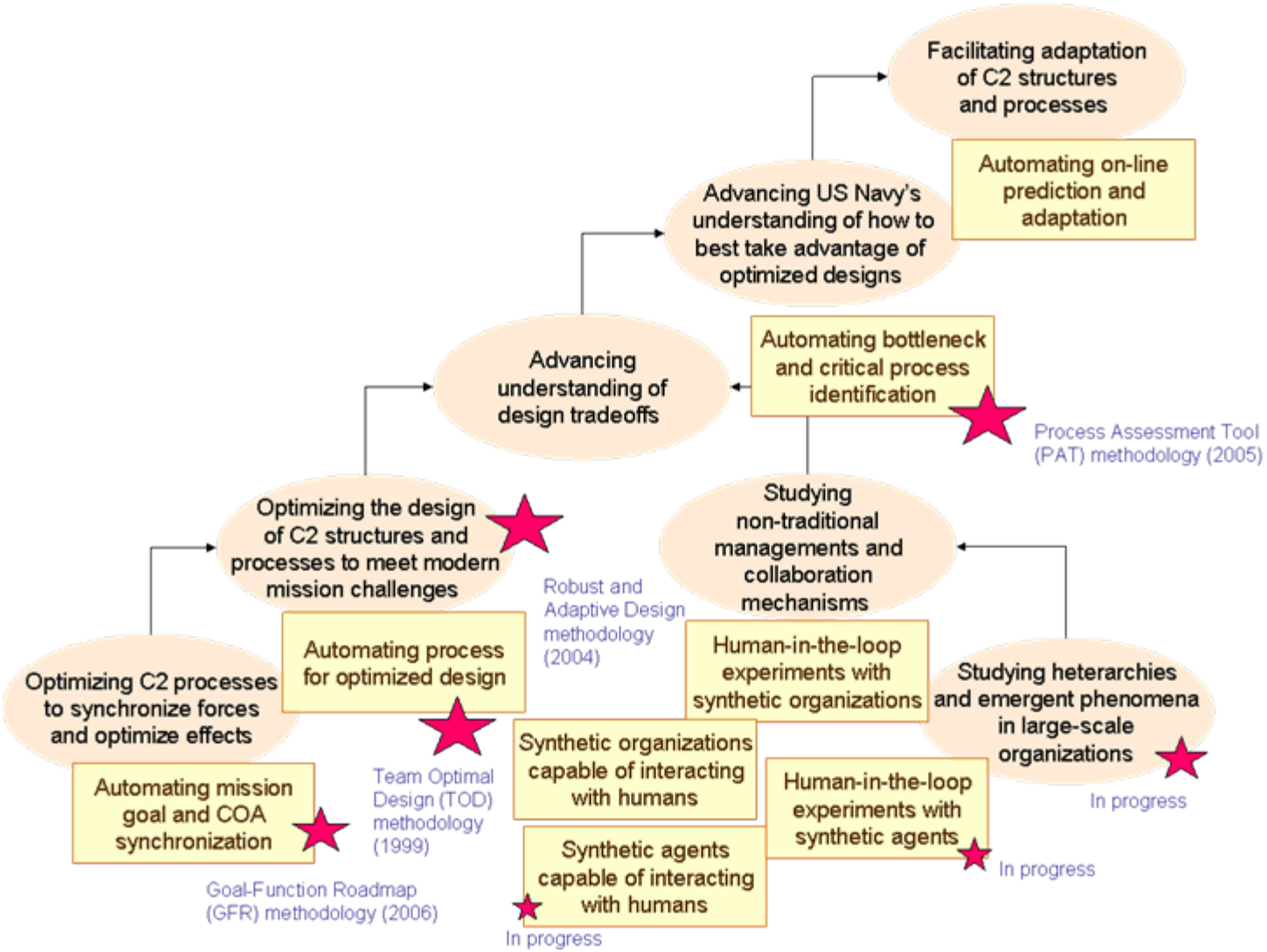
A2C2 Roadmap



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Summary

- Operationally-driven models
  - Models to address observed issues
  - Models to address complexity and facilitate A2C2 research
  - Hybrid and integrated executable models
- Spiral model-based experimentation framework
  - Virtual human-in-loop
  - Constructive/computational
  - Compare and validate models
  - Hybrid experiments
  - Agents as information providers/decision support, planners, task processors

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