



# **Integration of Holarchy and Holonic Scheduling Concepts for C<sup>2</sup> Organizational Design**

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# Outline

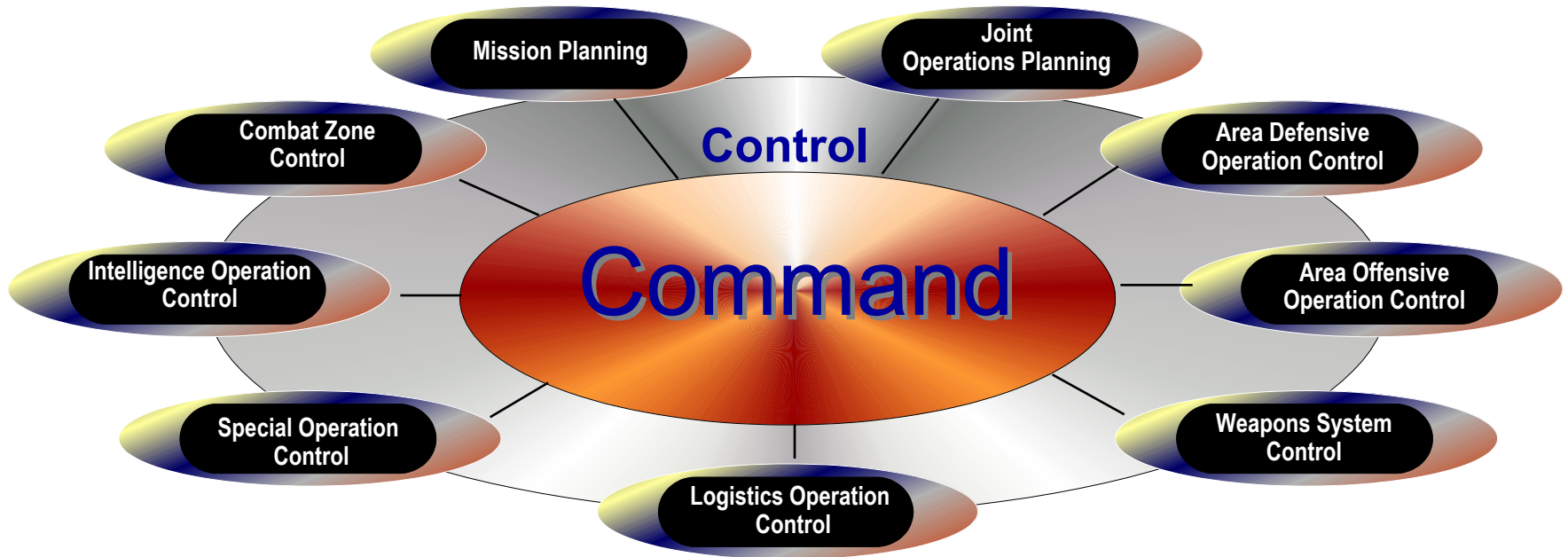
- ❑ C<sup>2</sup> Requirements for Unpredictable and Dynamic Mission Environments
- ❑ Traditional C<sup>2</sup> Structures
- ❑ Holonic Reference Architecture (HRA)
- ❑ Illustrative Example: Holonic Scheduling
- ❑ Summary and Future Work



# C<sup>2</sup> Requirements for Unpredictable and Dynamic Mission Environments

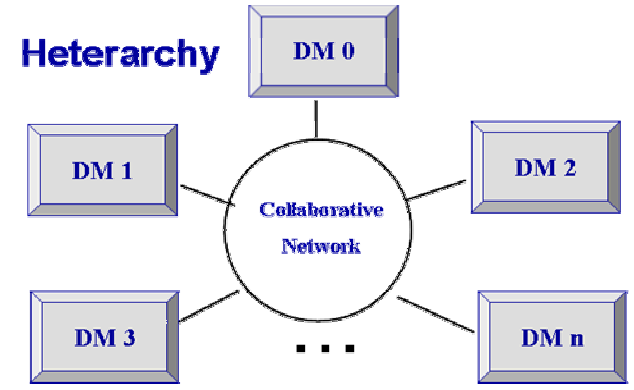
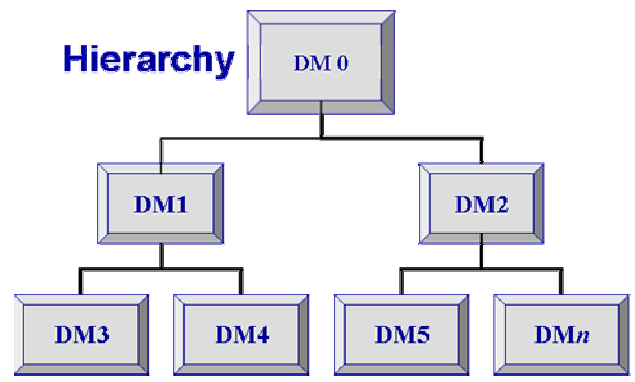
- Disperse organizational center of gravity among war-fighters ⇒ transfer organizational control to the lowest level
- Shift from a rigid **centralized** control – **decentralized** execution ⇒ flexible **decentralized** control – **decentralized** execution
- Broaden war-fighters' operational autonomy while maintaining overall mission objectives

⇒ Un-couple the organizational command and control





# Can traditional C<sup>2</sup> structures meet the challenges?



- Pros:**
- Unity of command
  - Efficiency under predictable conditions
- Cons:**
- Limited ability to reconfigure in novel situations
  - Rigid hierarchy ⇒ Slower response and limited immediate actions in the face of major disturbances
  - Multi-level bureaucratic structure ⇒ Limited information flow

- Pros:**
- Structural flexibility
  - Fast response to local disturbances
- Cons:**
- Absence of global information ⇒ Limited performance
  - Unpredictable organizational behaviors
  - Low efficiency of market-based negotiation mechanism ⇒ slow decision process
  - Limited emergent behaviors
  - Potential for chaotic behaviors

How do we overcome the drawbacks of the hierarchy and the heterarchy?

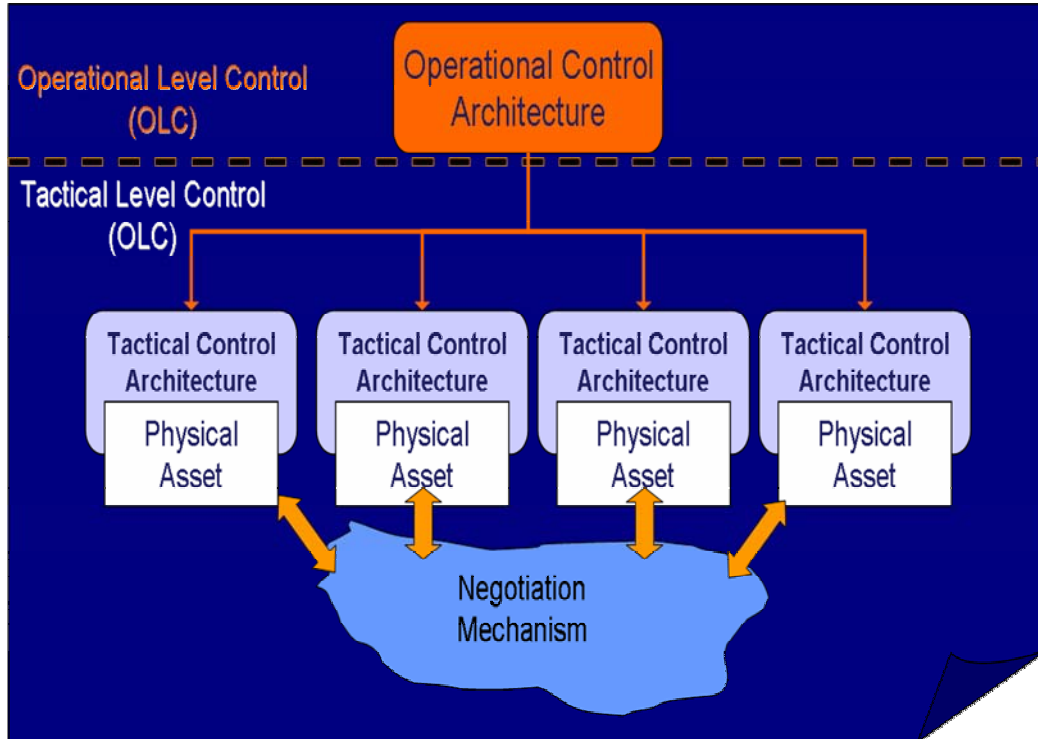


# Holonic Reference Architecture (HRA) – 1



## Holarchy:

- Combine positive features of hierarchy and heterarchy and mitigate their shortcomings: (a) ability to model very **complex** systems; (b) high **resiliency to** internal and external **disturbances**; (c) **adaptability** to changes in the environment
- Un-couple **command** and **control**:
  - **Command**: Operational Level Control (OLC)
  - **Control**: Tactical Level Control (TLC)
- Decentralize control  $\Rightarrow$  empower 'edges' of organizations
- Integrate the overall system  $\Rightarrow$  ensure unity of command



## Key Features of HRA

- **Autonomy** – distributed authority and control  $\Rightarrow$  facilitate local situation awareness, local decision-making, ...  $\Rightarrow$  **reactive and proactive behaviors**
- **Integration** – top-down authority and control flow  $\Rightarrow$  **unity of command**
- **Cooperation** – supervised coordination and negotiation mechanisms  $\Rightarrow$  **flexible interaction among units**  $\Rightarrow$  **minimum degree of disorders**
- **Self-Organization** – ability to cope with small shifts as well as major disturbances in mission environments
- **Flexibility** – individual units can be cloned or deleted as necessitated by the mission demands



## Tactical Level Control (TLC)

- Provide facility for *local scheduling, local situation awareness, negotiation mechanism and conflict resolution, and interface to physical assets*
- Focus on local sub-mission objectives
- Facilitate system flexibility  $\Rightarrow$  modular TLC units

## Functionality of TLC Holons

### Tactical holon (TAH)

Coordinate local units to work together to achieve local objectives

### Situational holon (SIH)

Provide local situational awareness

### Scheduling holon (SCH)

Manage local activities (schedule) for all units under the TLC authority

### Negotiation holon (NEH)

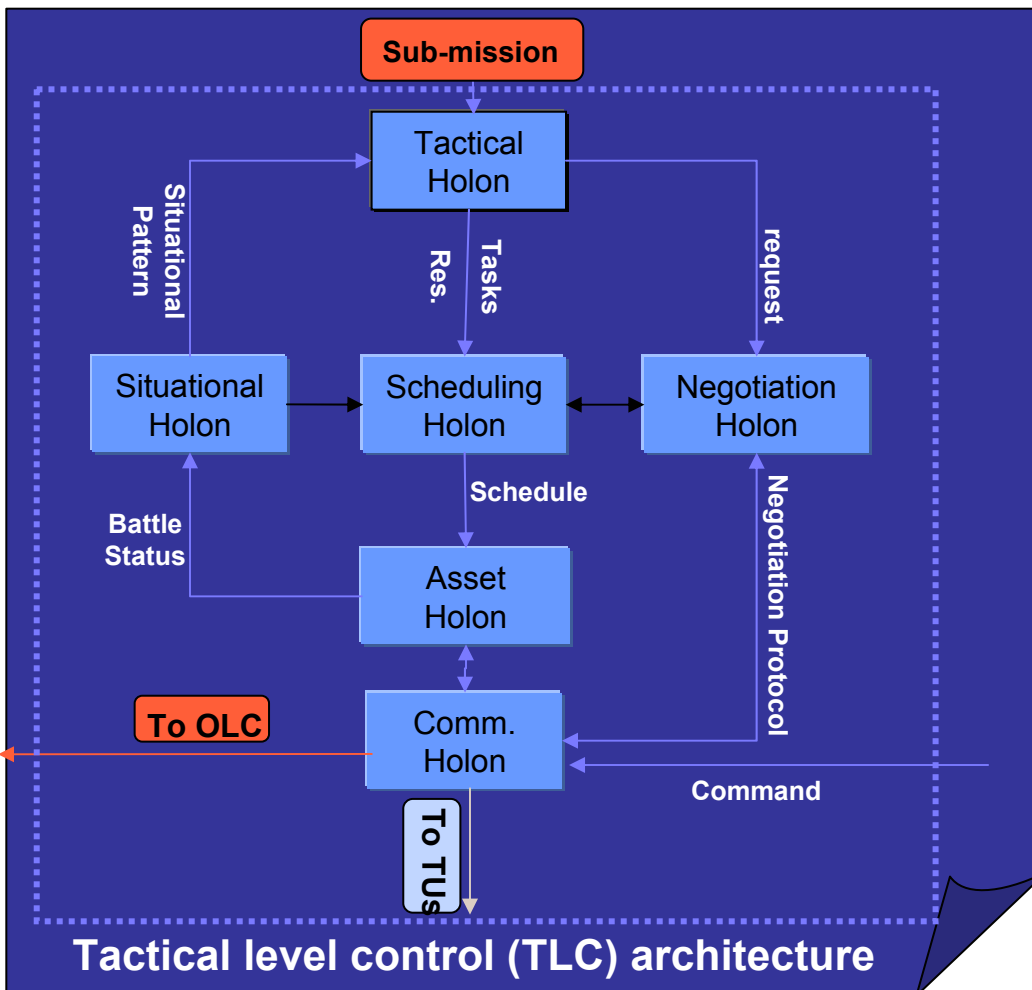
Coordinate with other TLC units and provide local conflict resolution

### Asset holon (ASH)

Provide interface facility between TLC units and the physical assets

### Communication holon (COMH)

Provides communication facility



Tactical level control (TLC) architecture



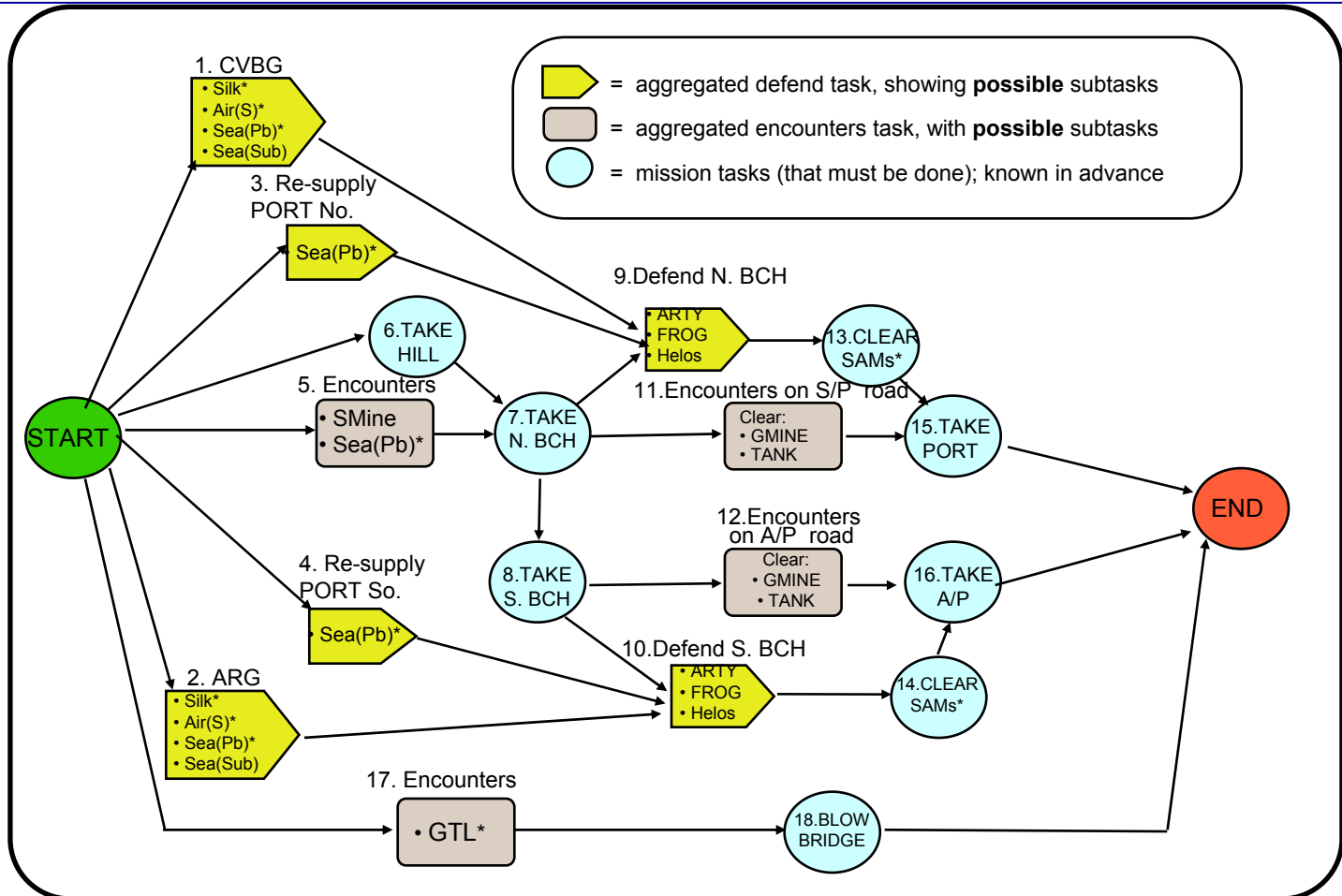


# Illustrative Example

**Mission:** Assign a joint group of Navy and Marine Forces to **capture Seaport** and **take Airport** to allow for the introduction of follow-on forces. Utilize two suitable **landing beaches: North Beach** with a road leading to the Seaport; and **South Beach** with another road leading to the Airport. Intelligence sources report **existence of hostile forces and potential counter-strikes**.

Input to OLC

Intermediate output of Operational Holon







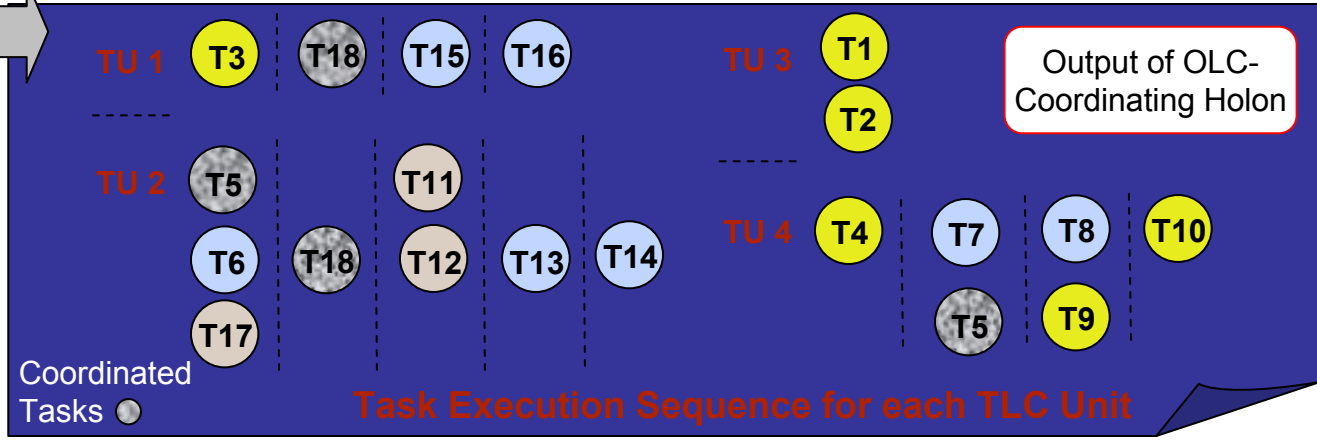
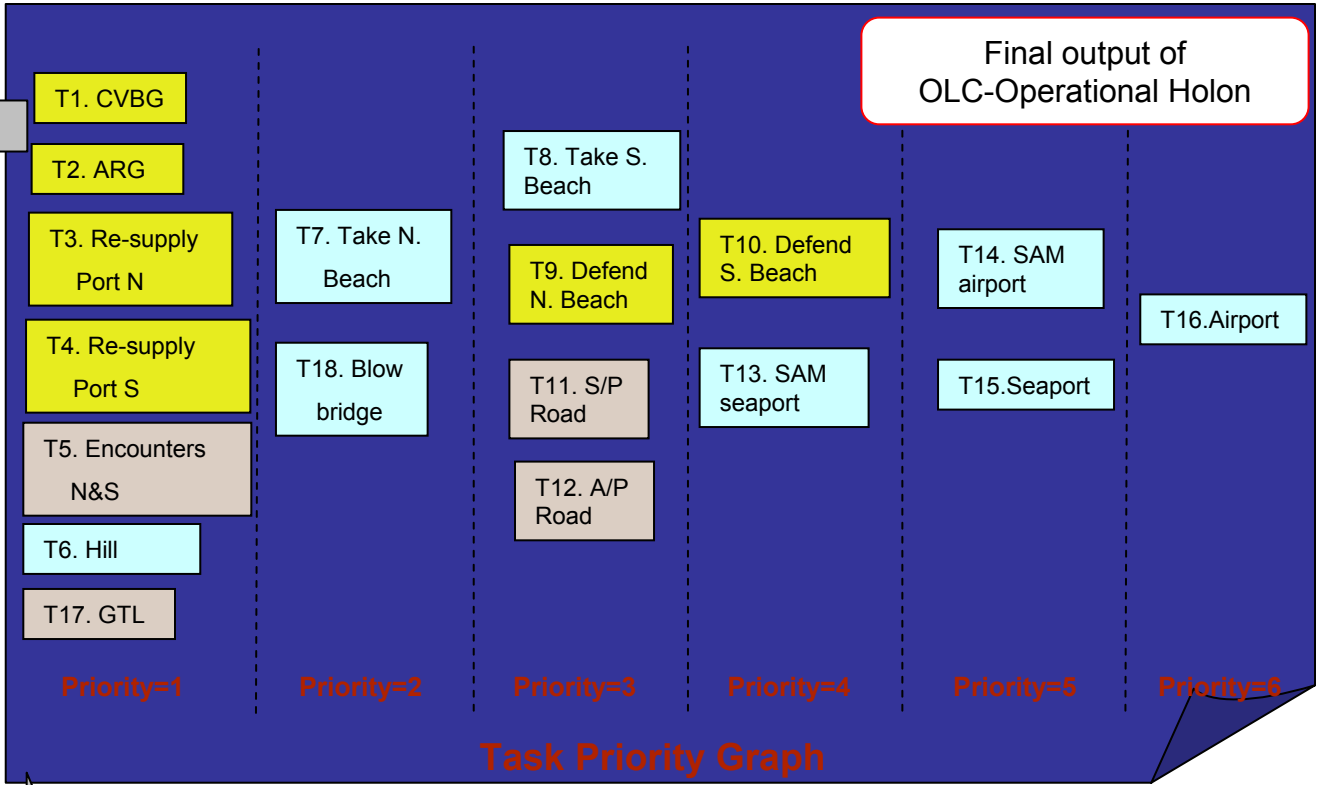
# Holonic Scheduling – 1

**Holonic Scheduling (Step 1)**  
**Deliberate Planning**  
 (output of OLC-Planning Holon)

- Optimal number of TLC units  $\Rightarrow$  4
- Sub-mission assignment to each TLC unit
- Asset allocation to each TLC unit
- Deadlines for tasks

**Holonic Scheduling (Step 2)**  
**Operational Level-Planning (multi-units)**

- *Coordinating Holon:*  
*Distributes the central plan to each local TLC units*
- Intelligence & Coordinating Holons: Monitors local TLC plans and ensures feasibility of the global plan
- Operational Holon: Responds to disturbances and directs TLC units for plan revisions





# Holonic Scheduling – 2



## Holonic Scheduling (Step 3) Tactical Level Scheduling

- ⇒ Distributed process
- ⇒ Each TLC unit generates sequential decisions based on local constraints, information, and objectives (e.g., minimizing make-span)

**Time Unit**

	Assets	0	1	2	3	4	5	6	7	8	9	10	
TU 1	P1	T3		T18							T15	T16	
	P15			T18									
	P18			T18							T15	T16	
	P19									T15	T16		
TU 2	P3	T6											
	P7	T6	T17		T11	T12	T13		T14				
	P11				T11	T12	T13		T14				
	P14		T5		T11	T12	T13		T14				
	P17		T17	T18									
P20	T6												
TU 3	P2	T1			T2								
	P10	T1			T2								
	P12	T1			T2								
	P16	T1			T2								
TU 4	P4		T5										
	P5			T7	T8								
	P6												
	P8	T4	T5	T7	T8								
	P9			T7	T8								
	P13					T9	T10						

Infeasible schedule due to precedence constraint violation

## Holonic Scheduling (Step 4) Reactive Scheduling

- Monitors feasibility of local TLC schedules
- Reinstates feasibility of the global schedule from infeasible local schedules
- Propagates adjustments to related TLC units ⇒ local *schedule regeneration* based on *new constraints*

**Time Unit**

	Assets	0	1	2	3	4	5	6	7	8	9	10	11
TU 1	P1	T3		T18							T15	T16	
	P15			T18									
	P18			T18							T15	T16	
	P19									T15	T16		
TU 2	P3	T6											
	P7	T6	T17		T11	T12	T13		T14				
	P11				T11	T12	T13		T14				
	P14		T5		T11	T12	T13		T14				
	P17		T17	T18									
P20	T6												
TU 3	P2	T1			T2								
	P10	T1			T2								
	P12	T1			T2								
	P16	T1			T2								
TU 4	P4		T5										
	P5			T7	T8								
	P6												
	P8	T4	T5	T7	T8								
	P9			T7	T8								
	P13					T9	T10						

Feasible Schedule

Feasible Schedule
  Coordinating Schedule
  Infeasible Schedule



# Summary and Future Work



- ❑ Introduce ***Holonic Reference Architecture (HRA)*** to model C<sup>2</sup> processes in unpredictable and dynamic mission environments
  - ❑ Un-coupled command and control ⇒ unity of command in a decentralized control system
  - ❑ Operational Level Control (OLC) provides a facility for mission decomposition, deliberate planning, command promulgation, and inter-unit coordination ⇒ unity of command
  - ❑ Tactical level control (TLC) oversees local scheduling, battlefield pattern recognition, and negotiation; and provides an interface to physical resources ⇒ decentralized control
- ❑ Numerical example shows that the C<sup>2</sup> HRA exhibits capability to detect and recover from schedule infeasibility ⇒ illustrate capability to cope with mission changes and ensure unity of command
- ❑ The illustrative example highlights the potential for HRA to facilitate *integration of centrality and autonomy; rigidity and flexibility; doctrine and adaptability* ⇒ suitable for modeling C<sup>2</sup> organization in the information age
- ❑ **Future Work**
  - ❑ Apply HRA principles to develop better analytical models of hierarchy, heterarchy, and holarchy, as well as, of the mission environment
  - ❑ Utilize HRA to model existing and future systems (e.g., Expeditionary Strike Group (ESG) and FORCEnet).



Thanks!