A Multi-Agent Decision Framework for DDD-III Environment

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Outline

Motivation

- Incorporate agent models of human decision-making processes to drive experiments with larger, partially or fully simulated, organizations
- Introduction to the third generation distributed-dynamic-decision-making (DDD-III) simulator
- Agent driven DDD-III simulation: a sample run

Three stage agent decision-making process

- Environment sensing
- Information processing
- Action selection: centralized and auction-based assignment

Results

- Scenario 1: Defend a friendly airbase
- Scenario 2: Part of A2C2 experiment 8

Why Agent-based Models?

Challenges:
- Large-scale experiments (human & synthetic agents)
- Analysis of large teams

Proposed Method: *Intelligent agent network* by utilizing analytic model–based algorithms in UConn's organizational design process and human cognitive limitations/biases embedded.

What constitutes an *intelligent agent*?
- Flexible autonomous agents
- Goal oriented
- Task knowledge/skills

What is a multi-agent network?
A loosely coupled network of agents that work together to solve problems that are beyond the individual capabilities or knowledge of each problem solver.

- Agent Model: Stimulus Hypothesis Option Response (SHOR, Wohl, 1980s)– based cooperative agents
- Multi-Agent Architecture: Heterogeneous communicating network with a flexible control architecture (hierarchy, heterarchy, or hybrid) to optimize a set of objectives (i.e., minimize completion time, minimize internal–external workloads, maximize total gain, etc.)
- Embed agents into DDD-III simulator

Task Execution in DDD-III Simulator

DDD-III simulator provides a controllable, multi-player, multi-platform, real-time organizational environment

A set of humans or agents or hybrid-humans-agents working together as a team are responsible to execute a set of tasks

Each player represents a decision-maker (DM)

Platforms: physical assets (e.g., ships, helicopters, Ground units, bases, etc.)

DM-Resource capabilities

Task execution by collaborating platforms

4 resource types; 3 units of type 2 and 3 units of type 4

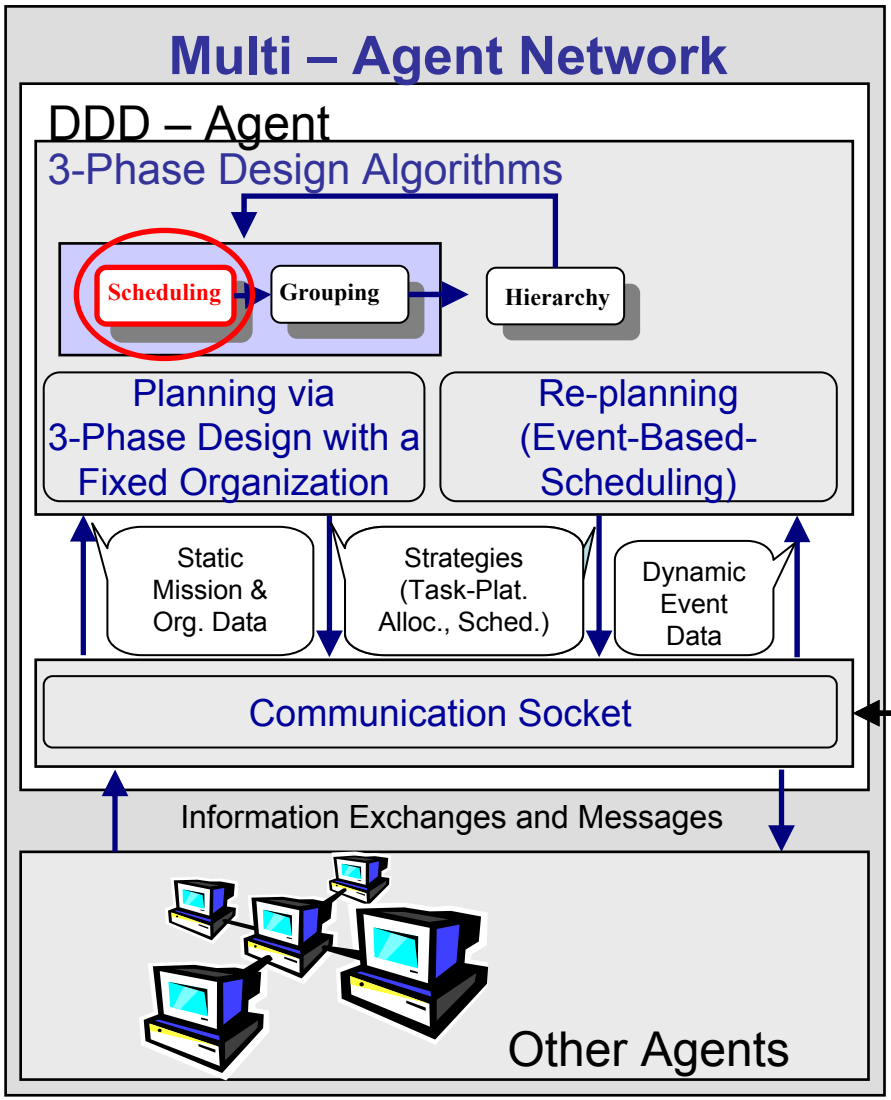
Task execution by a single platform

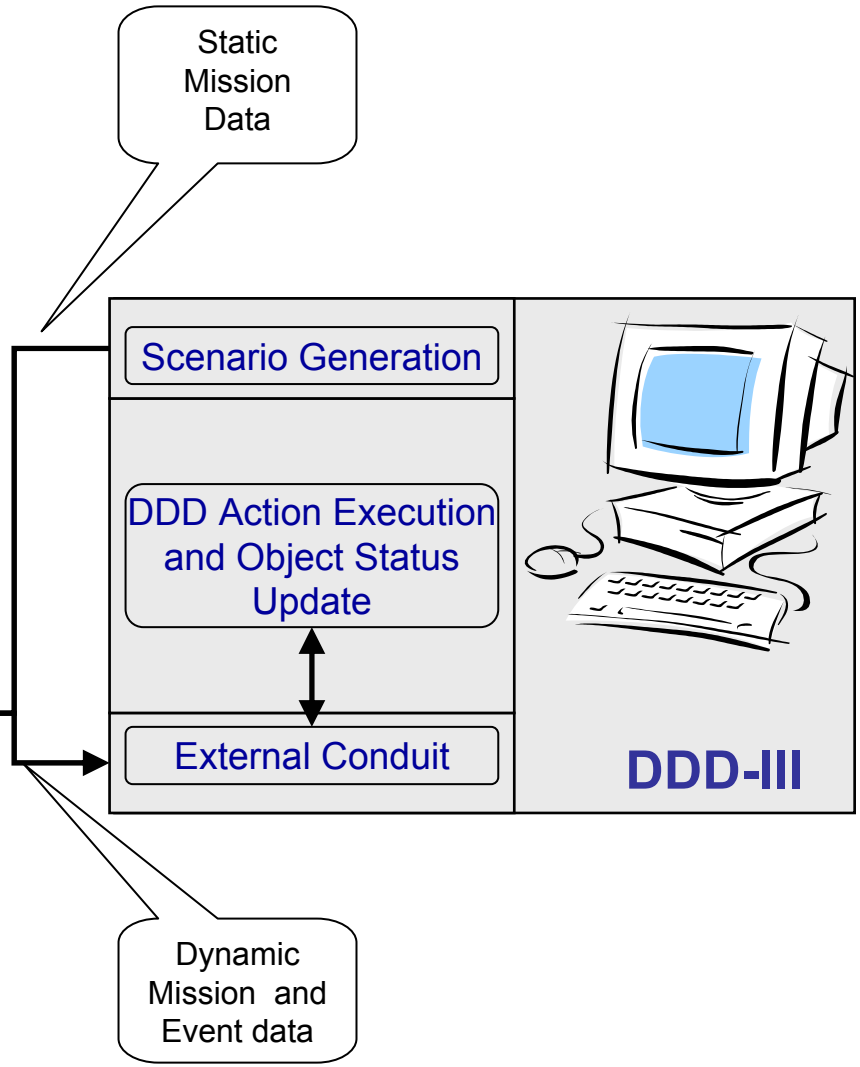
	P1	P2	P3	T1
	0	1	0	0
	3	0	3	3
	0	0	0	0
	3	2	1	3

Tasks: (e.g., hostile fighter, minefield, friendly fighter, etc.)

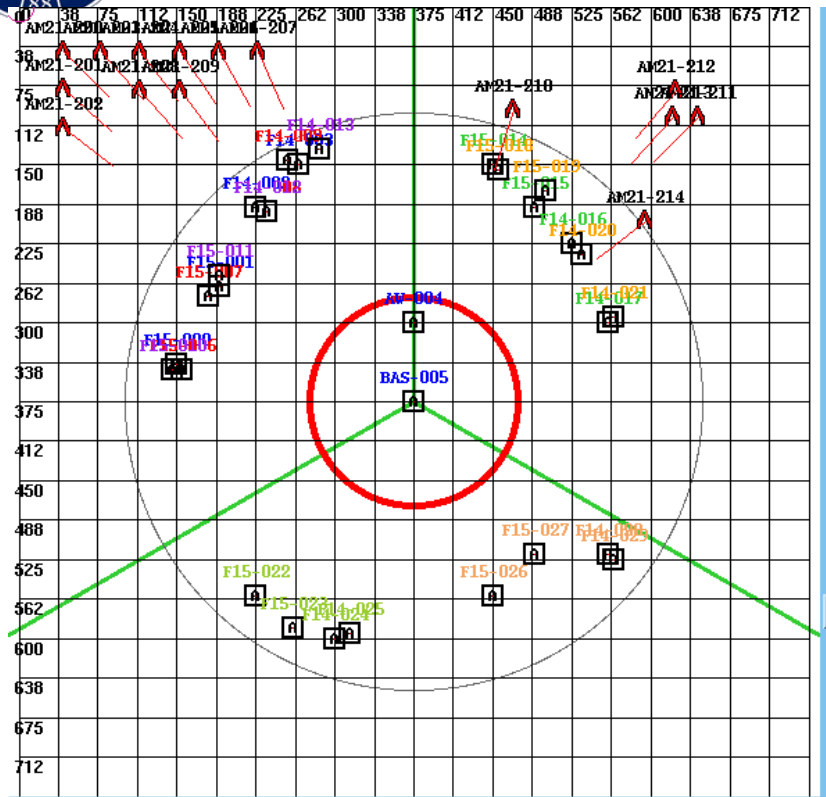
Task-Resource requirements

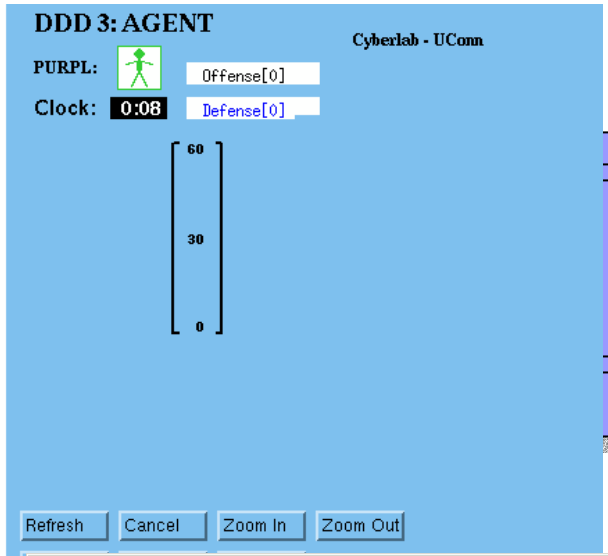
Integrated Framework

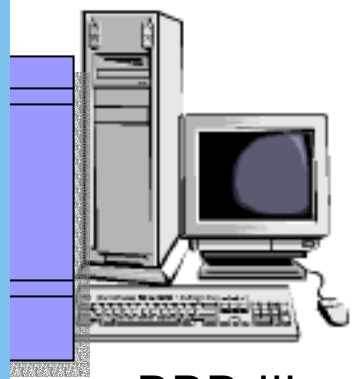




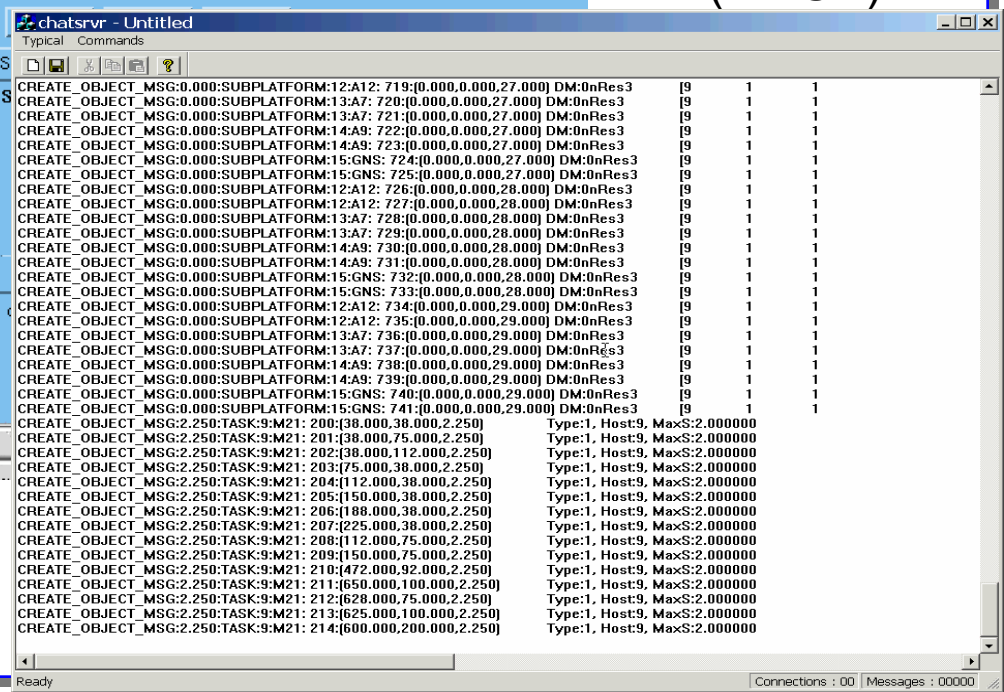
DDD Agents Within DDD-III Paradigm







DDD-III (LINUX)



Three-Stage Agent Model

Environment Sensing (ES)

- Receives information about existing objects (tasks, assets, and other DMs) from DDD via external conduit
- Inquires and receives information about existing objects from DDD or other DMs via the communication link

Information Processing (IP)

Processes information via a set of computational algorithms based on limited knowledge of environment (errors in estimating Task-resource requirements, errors in task and asset locations, limited knowledge of other DMs' capabilities, etc.)

Action Selection (AS)

- Selects actions according to a set of algorithmic rules
- Dynamically updates its schedule as new information becomes available

Environment Sensing Sub-model

Are there other members in the team?

Who owns what?

Are there any tasks within detection range?

Can they be identified as hostile or friendly?

Can their resource requirements be measured?

Who should be notified?

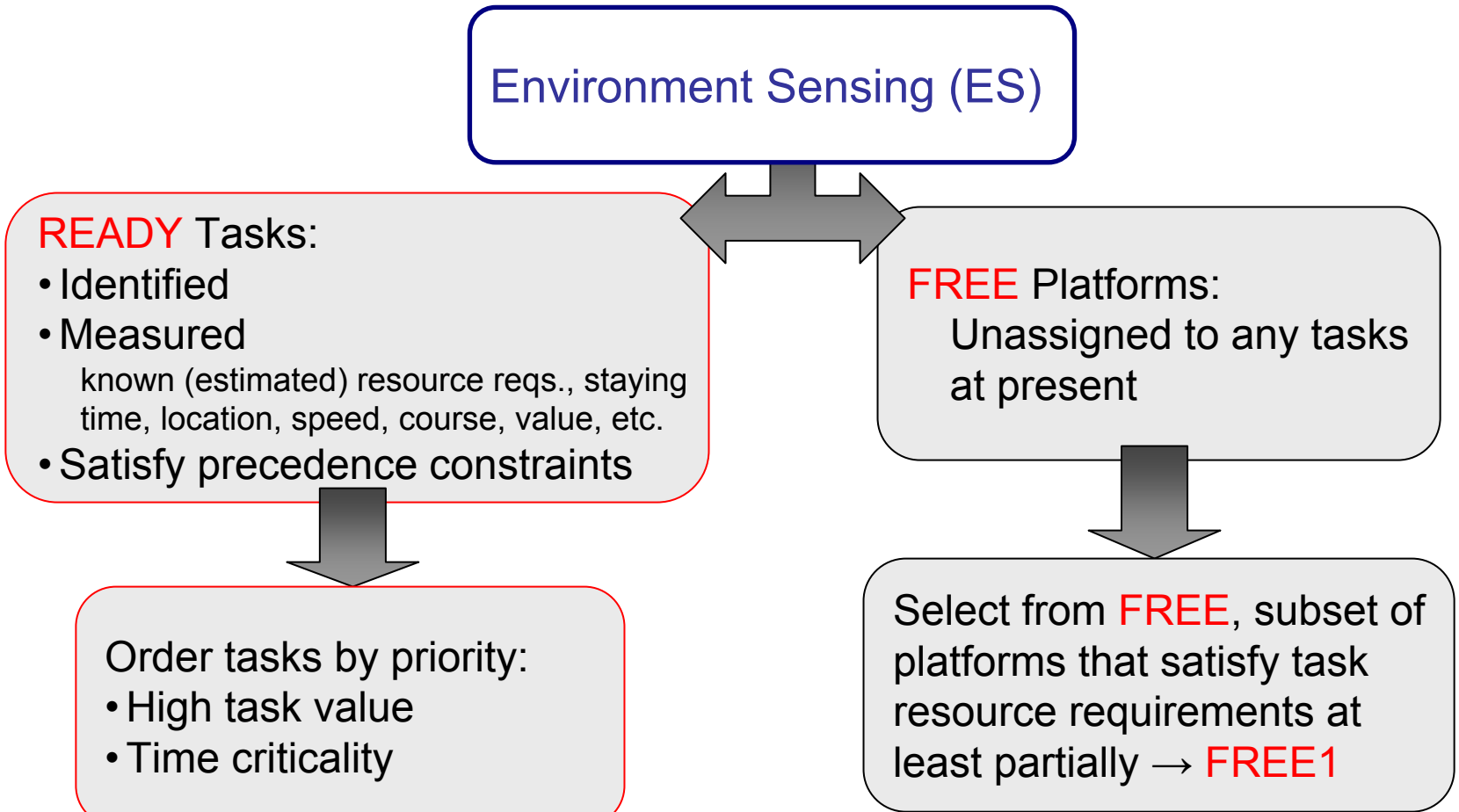
All subordinates of the current DM and his superior?

All of the team members? ⇐ Simplify communication pattern (suitable for centralized C2)

Potential coordinating partners? ⇐ Suitable for distributed C2

Information Processing Sub-model

Centralized implementation
Addresses the question of 'what should be done now?'



Action Selection Sub-model

Addresses the question of 'who should do what and when?'

Periodic
OR
Event Driven

WHILE READY is not empty:
    Select from READY a task *i* with the highest priority

    WHILE *i*'s resource requirements are not satisfied
        Select from FREE1 a platform with the highest execution accuracy and minimum impact on other tasks
    END WHILE

    Add task to ACTION queue
END WHILE

WHILE ACTION is not empty:
    Select from ACTION a task *i* (breadth first)

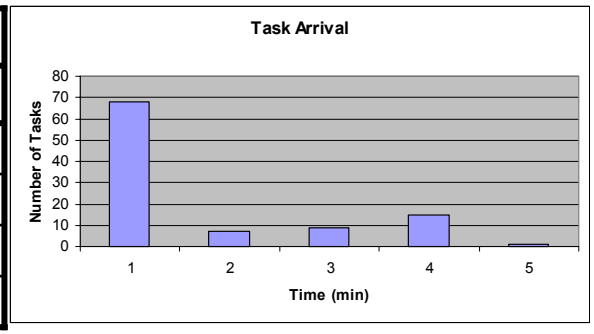
    Execute *i*: Move closer, pursue, attack, coordinated attack, etc.
END WHILE

Scenario 1: Defend a Friendly Airbase (1)

Scenario:

- A team of 7 identical DMs defend a friendly airbase
- One hundred tasks arrive randomly from random directions

Each DM			
8F15	4F14	1AW	1BAS
2A12	2A12	XXX	1F14
2A			1F15
			XXX
			XXX



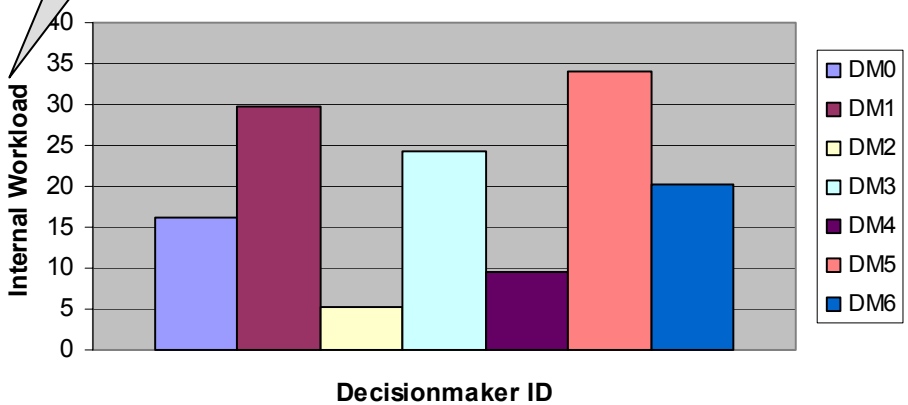
Aggregated operating assets of a DM

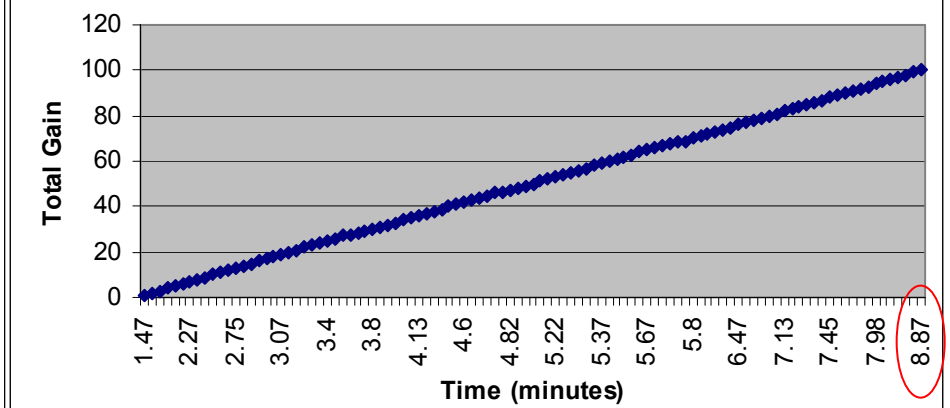
Performance Measures:

- *Accrued Gain Over Time*: Measure of team efficiency in processing tasks → accuracy and timeliness
- *Workload Distribution Among DMs*: Balanced workload over all DMs is desired. Higher workload and increased differences in workload lead to degraded organizational performance

Wo ad distribution is not balanced → Processing time: 8.87 minutes

Why ?



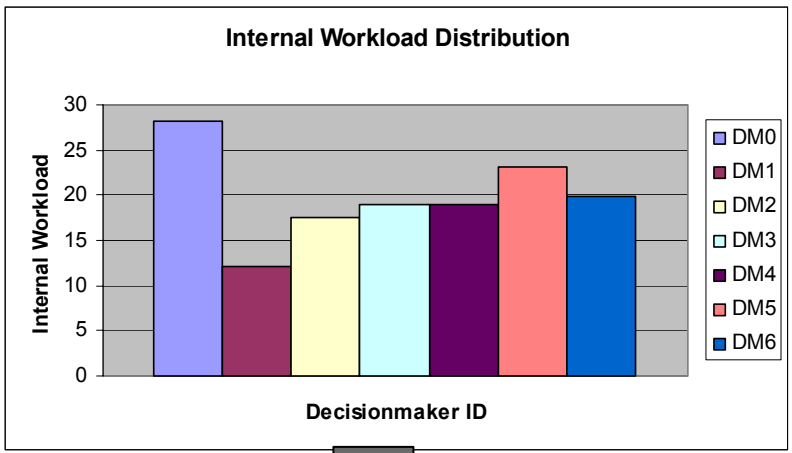


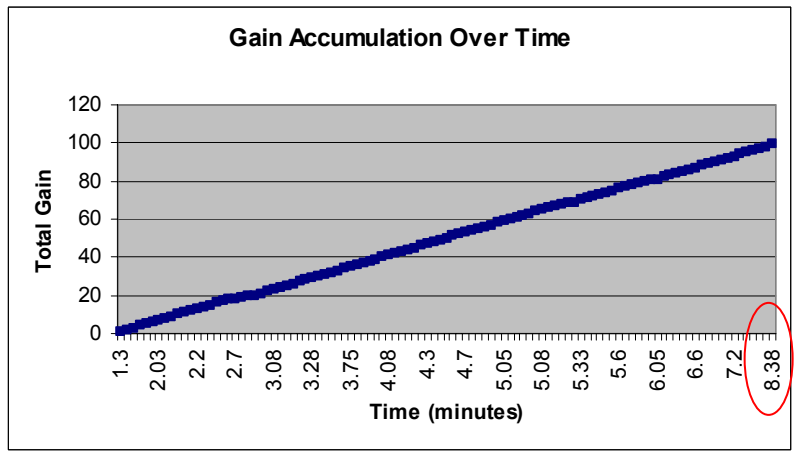
Scenario 1: Defend a Friendly Airbase (2)

- Basic strategy: DMs have identical capability to undertake the incoming tasks → handle tasks with minimal effort (fuel efficiency) → minimum platform-to-task distance

- Uneven platform spread among DMs → uneven platform-to-task distances among platforms belonging to different DMs → increased workload disparity

- Strategy adjustment: Better initial platform placement → more balanced workload distribution among DMs





Balanced workload distribution

Lower processing time: 8.38 minutes (6% improvement)

Example 2: Part of A2C2 Experiment 8

A team of 6 heterogeneous agents coordinate to execute a set of 15 complex tasks
(with values ranging from 0 to 50)

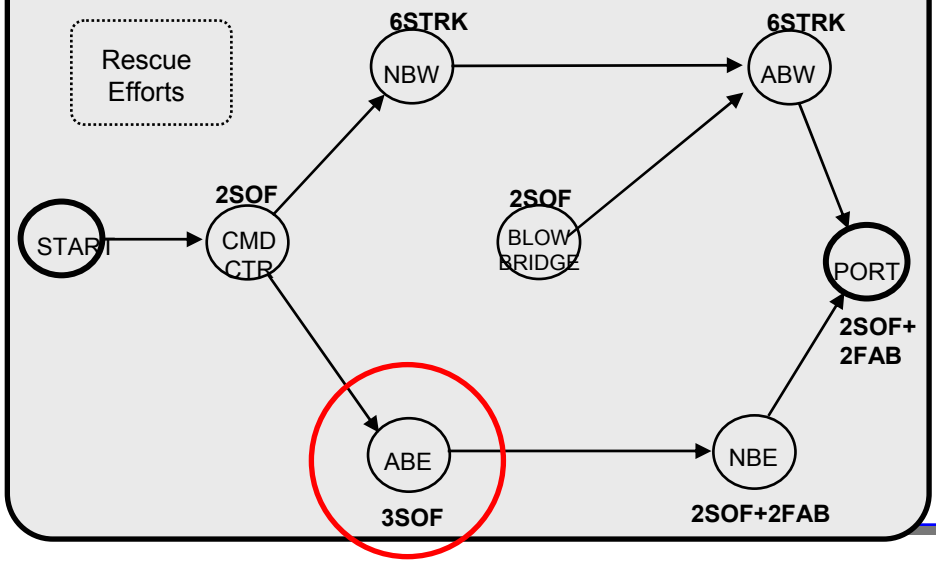
F

D

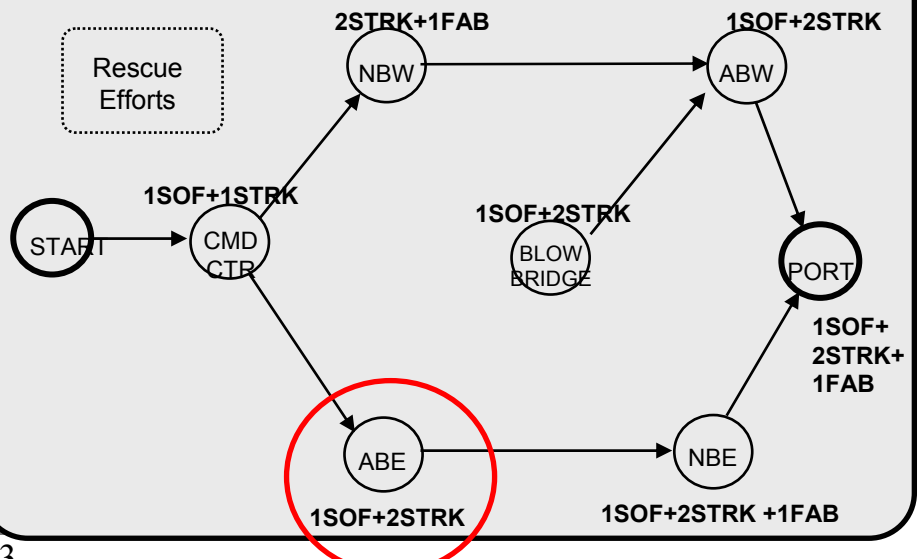
			FUNCTIONAL					
DIVISIONAL	DM		1	2	3	4	5	6
		Platform	STRIKE	BMD	ISR	AWC	SuWC/MINES	SOF/SAR
	1	CVN	2F18S	xxx	1UAV	2F18A, E2C	1FAB, 1MH53	1HH60
	2	DDGA	8TLAM	3ABM,4TTOM	1UAV	6SM2	1FAB, 2HARP	1HH60,1SOF
	3	DDGB	8TLAM	3ABM,4TTOM		SM2	1FAB, 2HARP	1HH60,1SOF
	4	CG	8TLAM	3ABM			1FAB,2HARP,1MH53	1HH60
	5	FFG*	2F18S	xxx		4SM2	1FAB,2HARP,1MH53	1HH60
	6	DDGC	8TLAM	3ABM,4T			1FAB, 2HARP	1HH60,1SOF

Differentiated by resource requirements

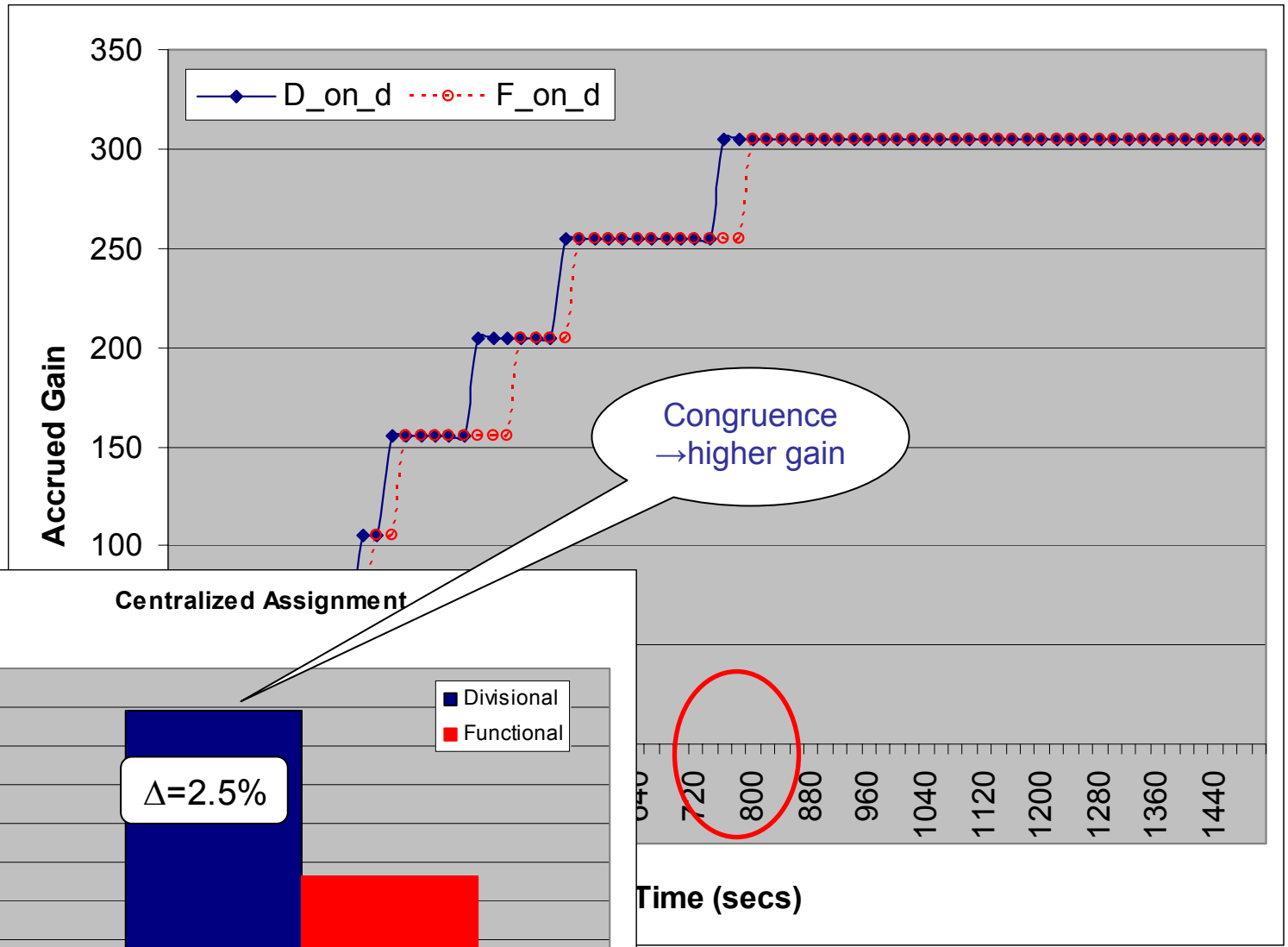
Functional Scenario - **f**



Divisional Scenario - **d**



Divisional Scenario (d): Accrued Gain

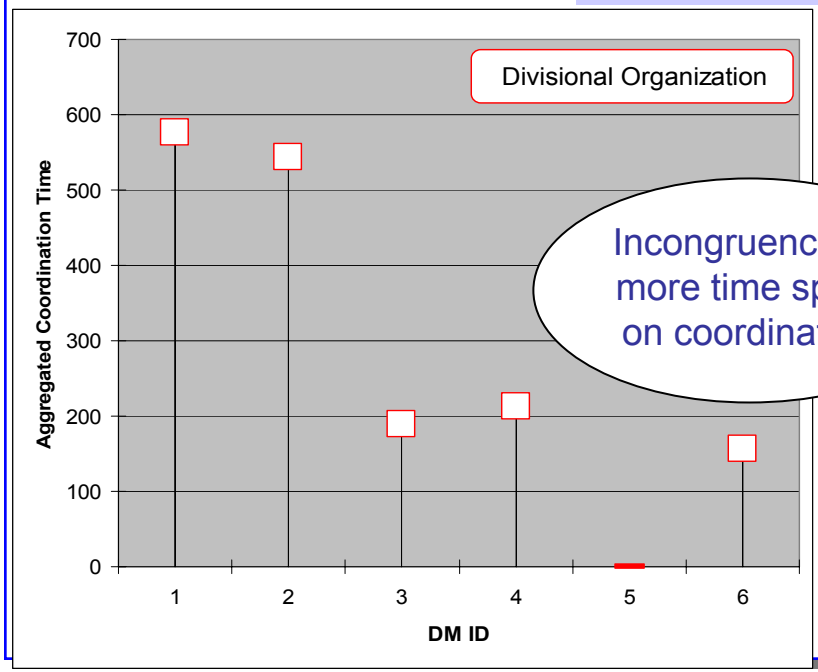


Divisional Scenario (d): Workload Distribution

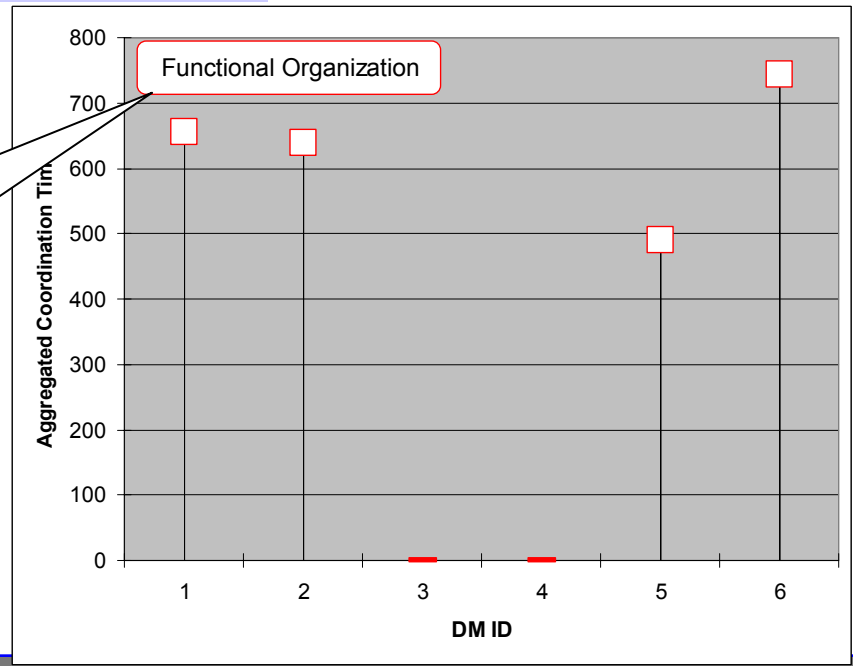
The *external coordination workload* of a DM is the sum of its direct coordination (aggregated time associated with simultaneous processing of the same set of tasks) with other DMs

$$E(k) = \sum_{l=1, l \neq k}^{N_{DM}} D(k,l)$$

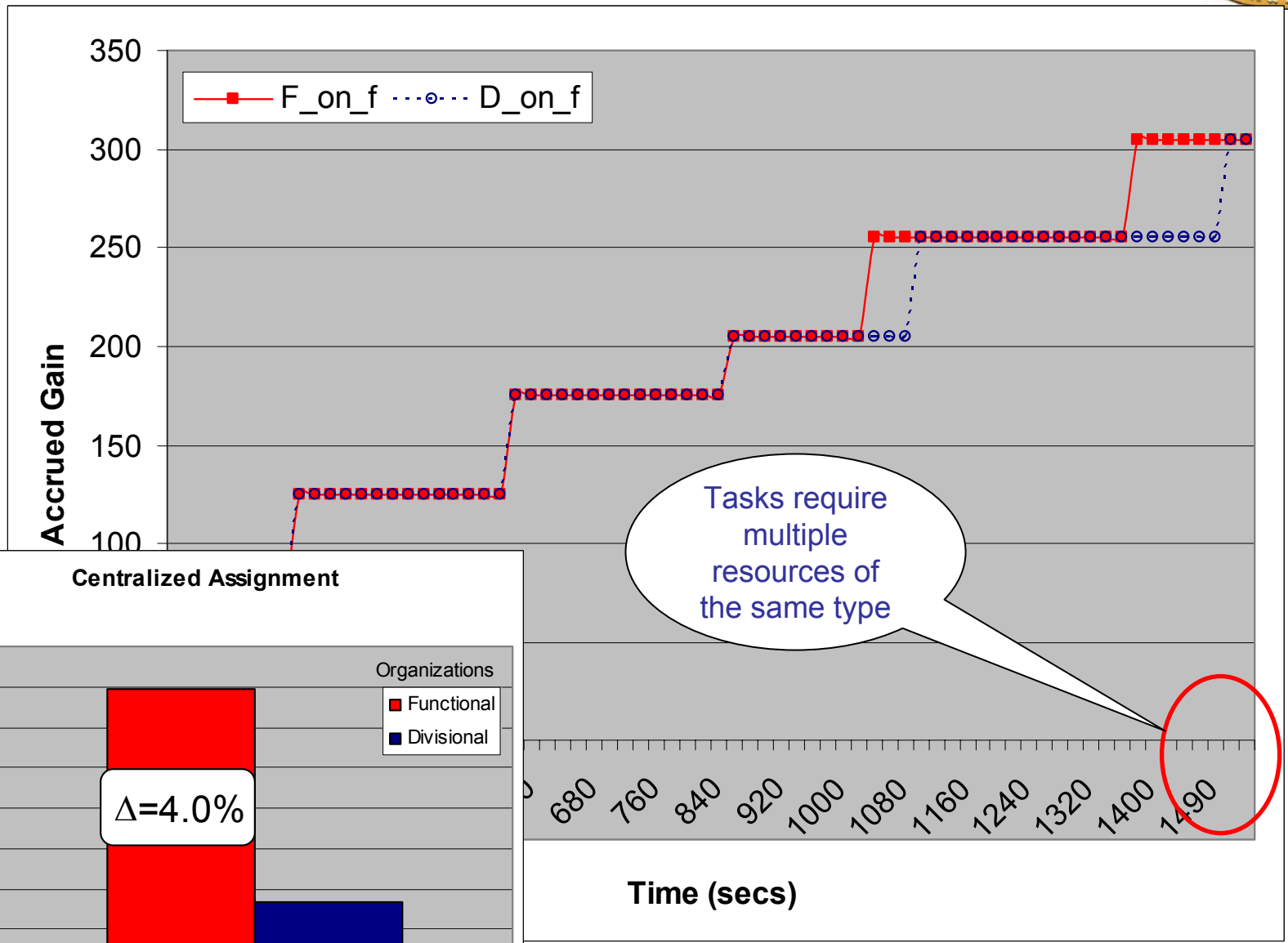
$$D(k,l) = \sum_{i=1}^{N_{Task}} \min(u_{ki}, u_{li}) \cdot t_i$$



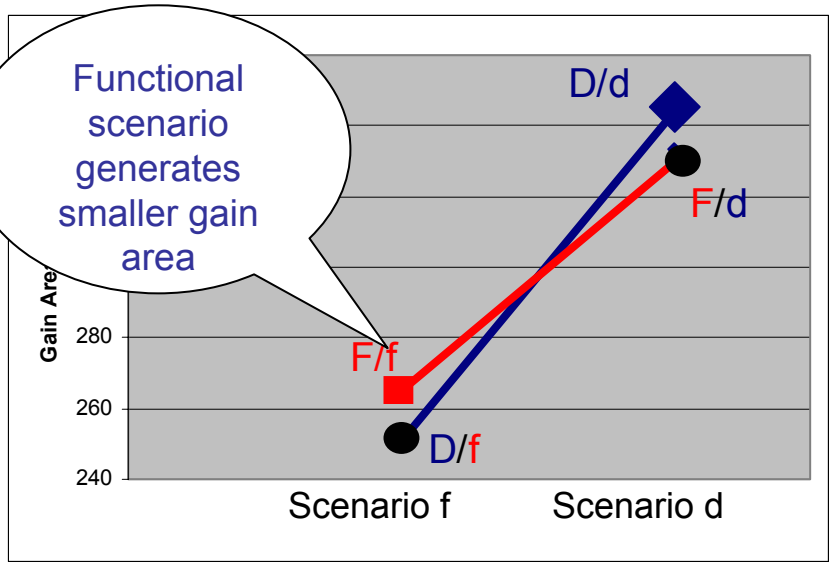
Incongruence → more time spent on coordination

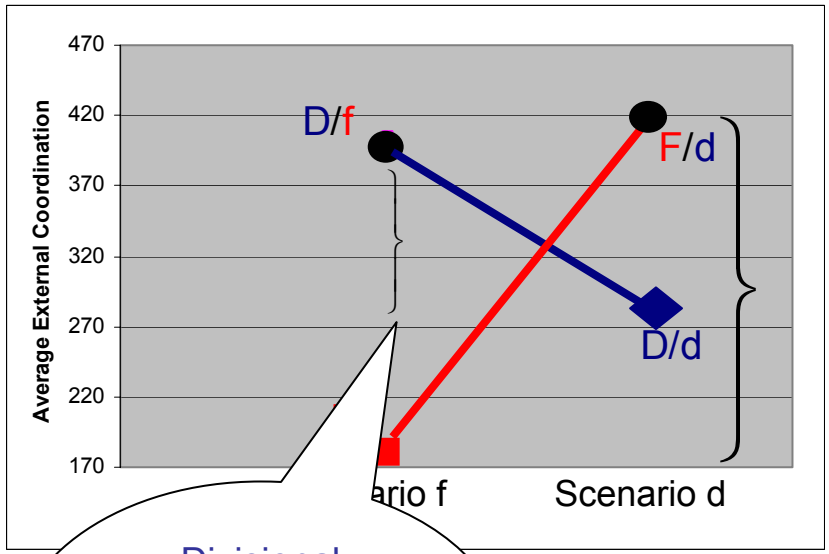


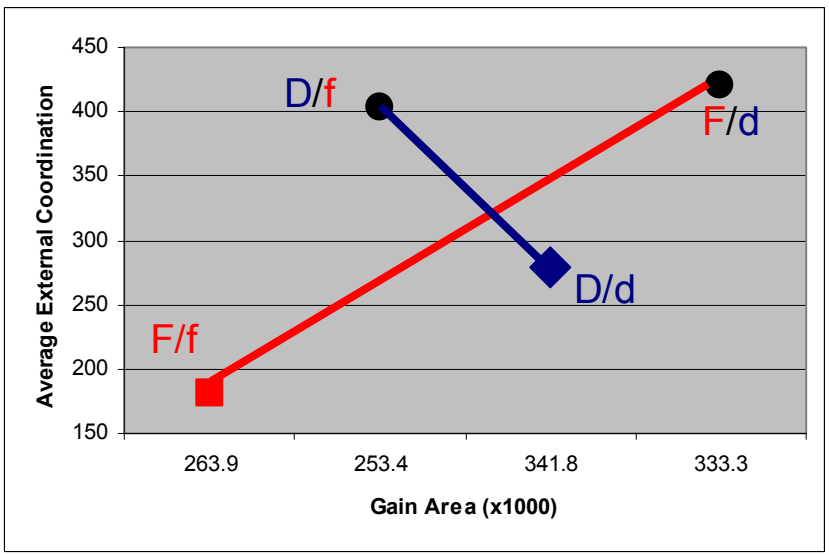
Functional Mission (f): Accrued Gain



Centralized Assignment: Performance Comparison







Divisional organization copes better with higher coordination requirement

Congruent with **Divisional Organization**

Incongruent Organization-mission pair

Platform-to-Task Allocation via Auction

Match buyers to sellers to minimize
sum of *excess prices*
↔
A task selects the 'best' subset of platform(s)
Each platform is assigned to the 'most attractive' task

Task (buyer):
Find cheapest
available price

Platforms (sellers):
Find highest offered
price

Price adjustment:

- Platform sets a current price
- Task adjusts its offer

Action Selection via Auction

WHILE READY is not empty:

Auction Initialization

Add task to **AUCTION_READY** queue

END WHILE

Action Execution

WHILE READY is MATCHED:

Auction Process

Adjust the bid prices:

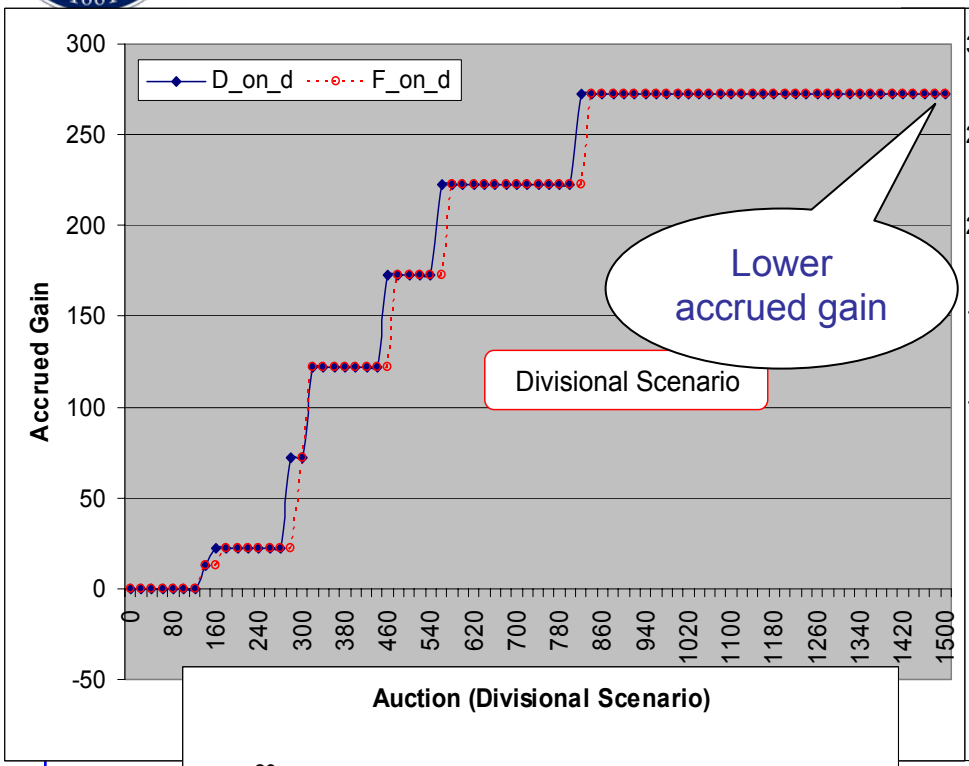
WHILE *i*'s resource requirements are not satisfied

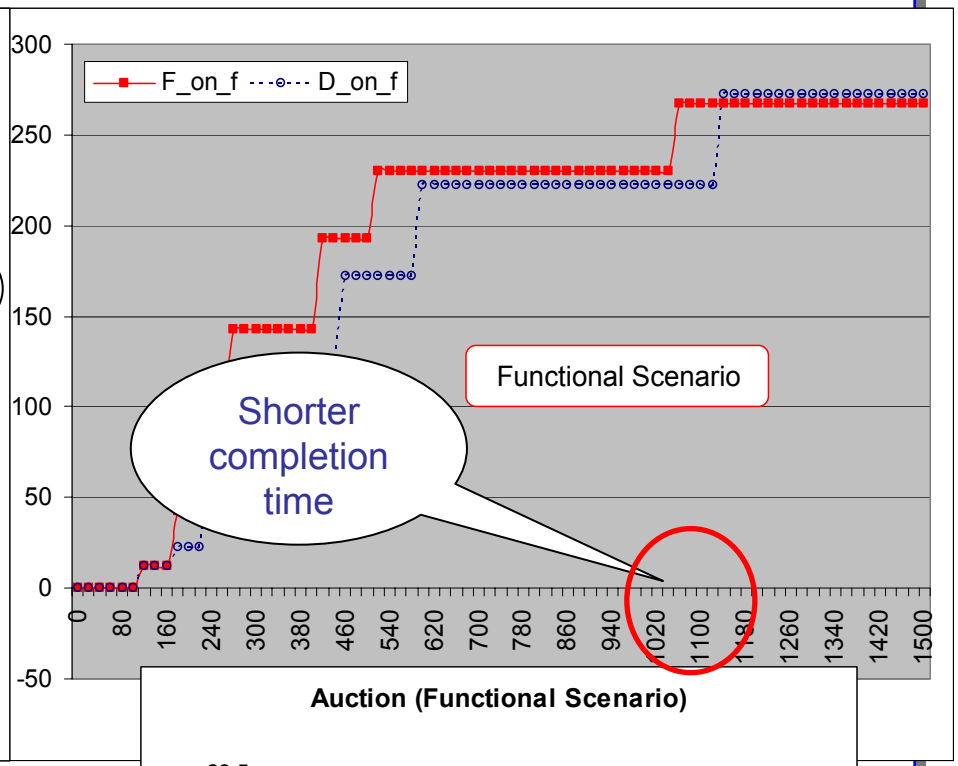
Select to bid from FREE1 a platform with the highest execution accuracy and minimum impact on other tasks based on the adjusted prices

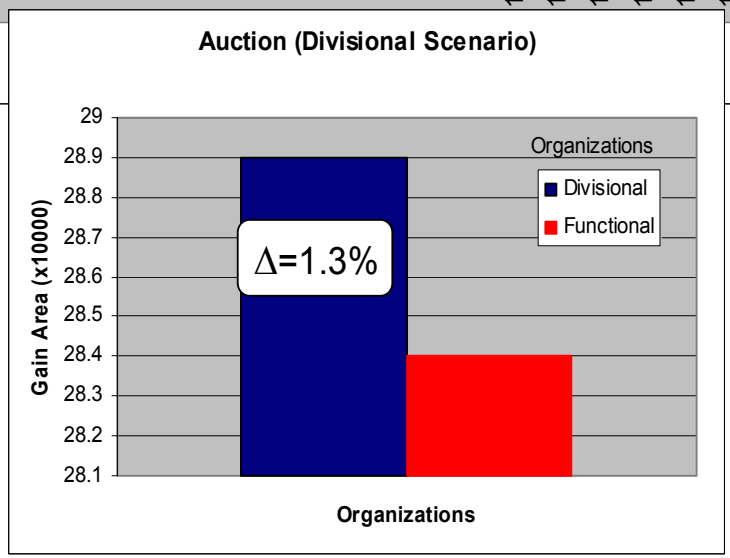
END WHILE

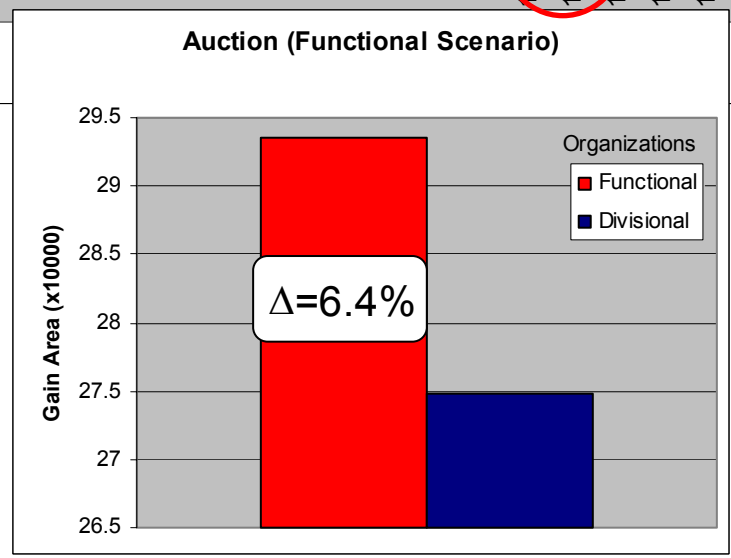
END WHILE

Accrued Task Gain

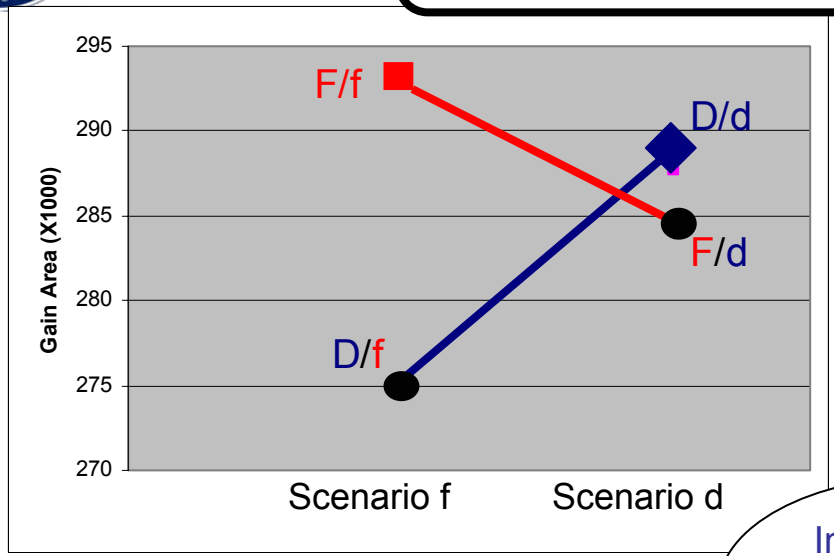


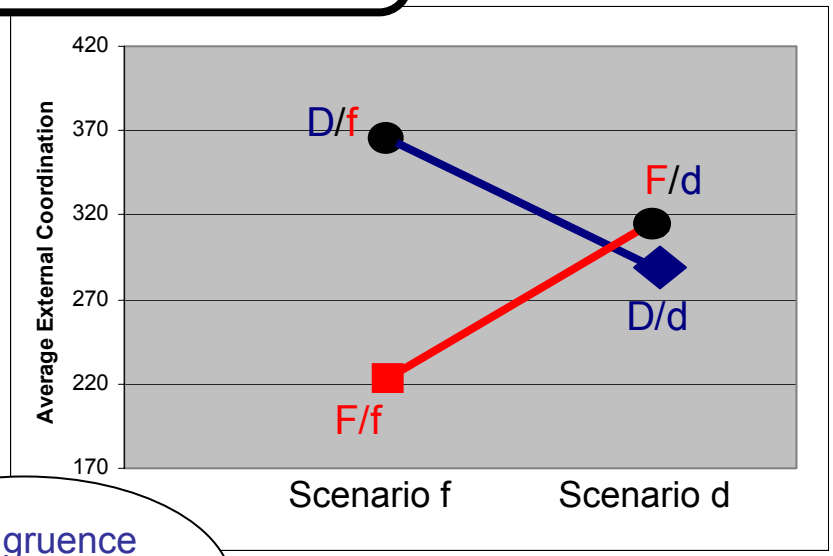




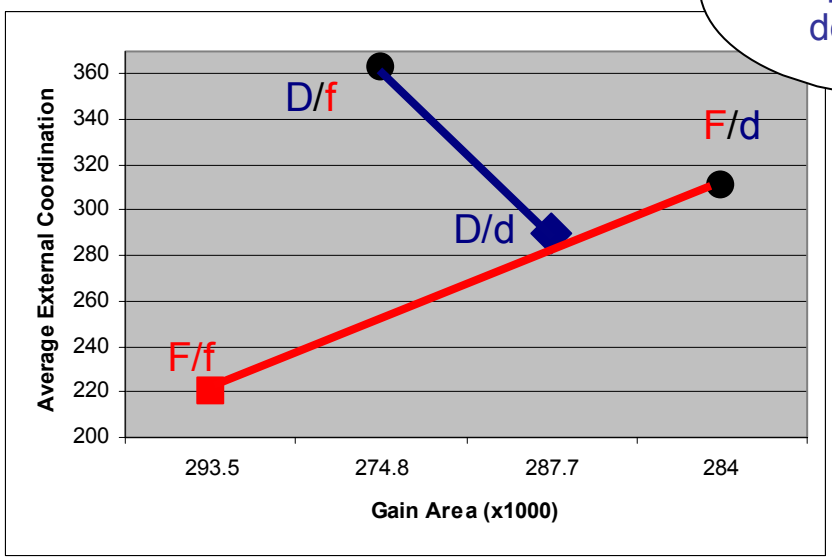


Auction-based Assignment: Performance Comparison





Incongruence → performance degradation



- Congruent with **Functional Organization**
- Congruent with **Divisional Organization**
- Incongruent Organization-mission pair

Summary and Future Work

- Results from the DDDIII-based agent framework demonstrate the potential of utilizing agents to drive large-scale C2 experiments
- Extend the implementation to *distributed* decision-making processes via limited look-ahead, *improved* auction-based algorithm
- Incorporate human cognitive limitations into the agent model to simulate more realistic decision-making processes
- Extend the system to an integrated, dynamic, decision support system