Distributed Auction Algorithm for the Assignment Problem with Partial Information

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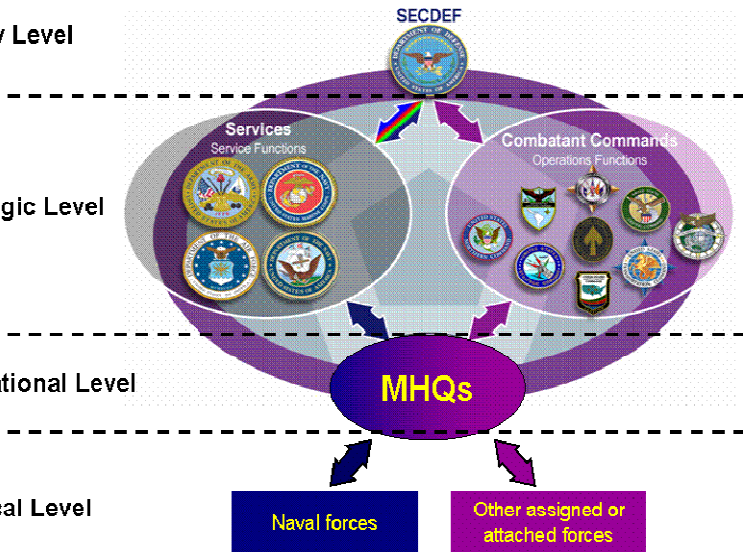
Introduction

jective & Motivation

Develop analytical and computational models for multi-level **collaborative mission planning** and monitoring processes associated with Maritime Operations Centers (MOC*)

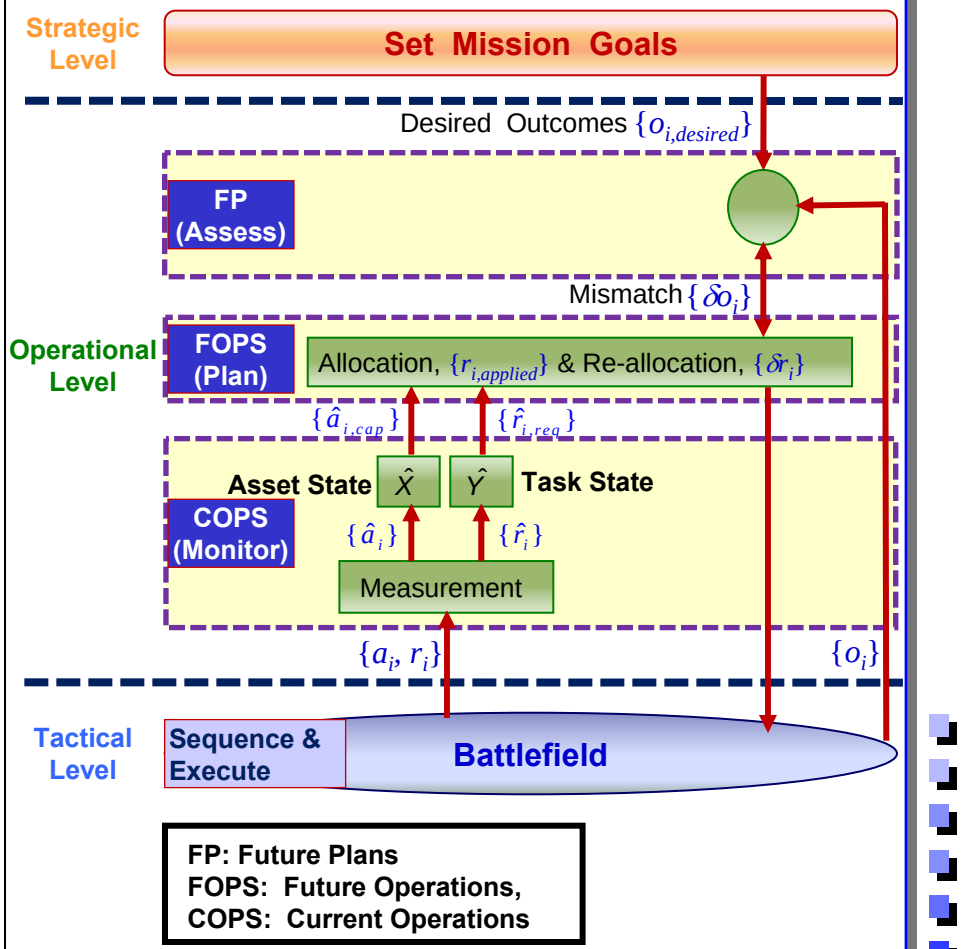
In MOC, multiple DMs with **partial information** and **partial control over** assets are involved in the development of operational level plans

*MHQ/MOC



Collaborative Mission Planning Problem

- **In the collaborative planning problem**, each DM "owns" a set of assets and is responsible for planning certain tasks

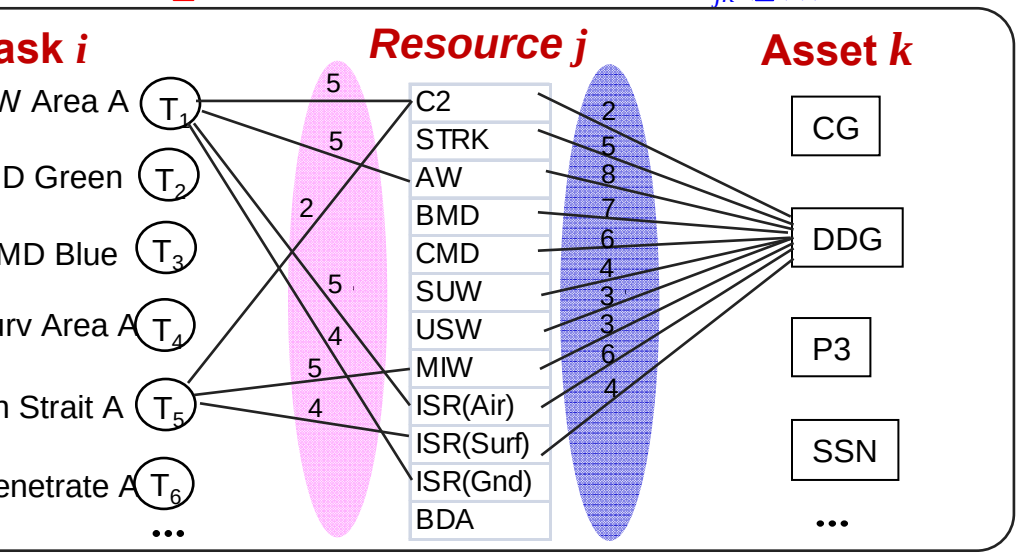


Task-Asset Assignment Problem

Task and Asset States

Task Requirements $r_{ij}(\hat{\underline{y}}(t))$

Asset Capabilities $a_{jk}(\hat{\underline{x}}(t))$



- r_{ij}: Requirement j of task i, given the task state $\hat{\underline{y}}(t)$ at time t
- a_{jk}: Asset Capability j of asset k given the asset state $\hat{\underline{x}}(t)$ at time t

- The degree of match between the task-resource requirement vector and asset-resource capability vector determines the accuracy of task execution
- The distributed assignment problem with partial information considered next is a simplified and abstracted version of the collaborative planning problem

Legend	Description	Legend	Description
AEW	Airborne early warning	USW	Undersea warfare
AMD	Theater air/missile defense	BDA	Battle damage assessment
MIW	Mine warfare	ISR	Intelligence, surveillance and reconnaissance
C2	Command and control		
TRK	Strike	CVN	Nuclear aircraft carrier
AW	Air warfare	CG	Guided-missile cruiser
BMD	Ballistic missile defense	DDG	Guided-missile destroyer
CMD	Command	P3	Ant-submarine aircraft
UW	Surface warfare	SSN	Nuclear submarine

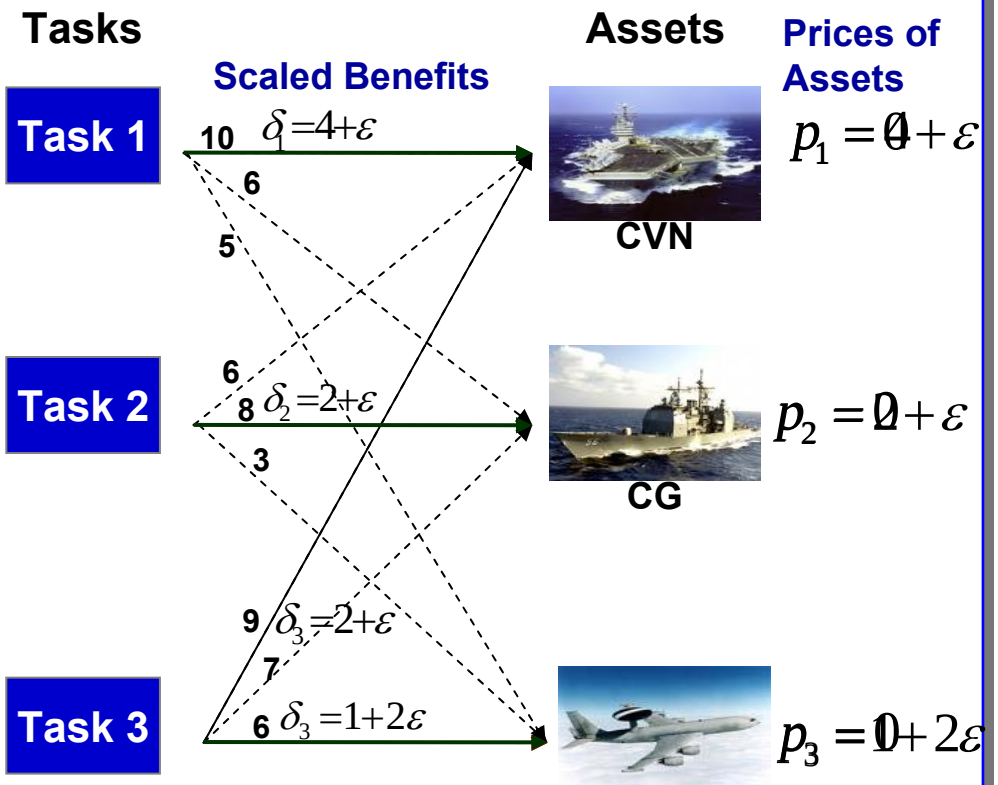
Auction Algorithm for Assignment Problem

Auction Algorithm for Assignment Problem

- **Objective:** Match *n* tasks to *m* assets to maximize a benefit function
- There is a benefit matrix $A = [\, a_{ij} \,]$; a_{ij} = benefit of assigning asset *j* to task *i*
- When *n=m,* it is called a symmetric assignment problem. Otherwise, asymmetric

Auction Algorithm Process

- **Bidding phase**: Each unassigned task *i* bids for an asset *j* with the best profit ($=a_{ij}$ – price of asset p_j) with a bid *d* equal to (a_{ij} – 2nd best profit +ε); ε<1/n
- **Assignment phase**: Each asset is assigned to the highest bidder (task) and adjusts its price to the highest bid



Novel Distributed Assignment Problems

Objective: Match *n* tasks to *m* assets to maximize a benefit function when DMs have only **partial information** of benefit matrix, *A*

Information Structures: Horizontal, Vertical, Block diagonal, Checkerboard

Assets

DM_1
DM_2
:
DM_M

Assets

DM_1	DM_2	…	DM_L

⟨Column⟩ info: Each DM
a set of tasks ⟨assets⟩, but
s benefits for all assets
s⟩

Assets

Tasks

DM_1	Coordinator
	DM_2
	DM_M

Block diagonal info: Each DM knows benefits for own task-asset pairs; Coordinator knows the rest

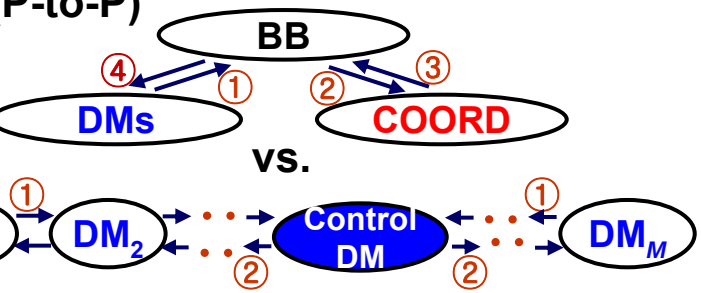
Assets

Tasks

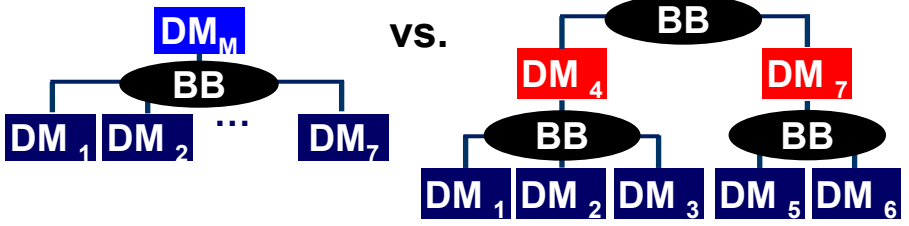
DM_{11}	DM_{12}	…	DM_{1L}
DM_{21}	⋱	…	:
:		⋱	:
DM_{M1}	…	…	DM_{ML}

Checkerboard info: Each DM knows benefits for own task-asset pairs

Communication Structures:
Blackboard (BB) vs. Point-to-point (P-to-P)

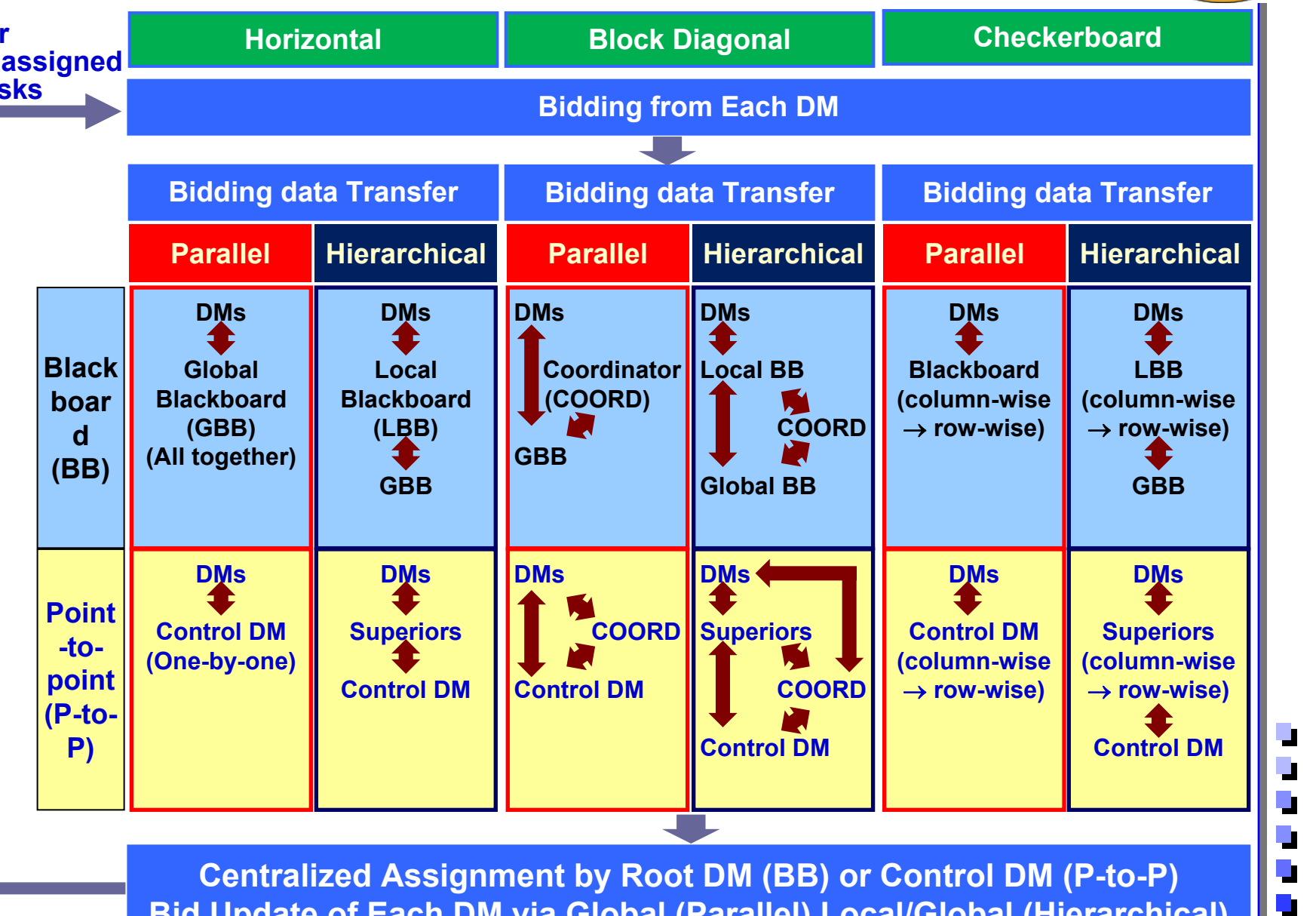


- **Organizational Structures:**
  Parallel vs. Hierarchical tree



Key Idea: **Can construct the centralized assignment solution by transferring bids and the best as well as 2nd best profits** toward the root DM (for BB) or the control DM (for P-to-P) even if DMs have **partial information**

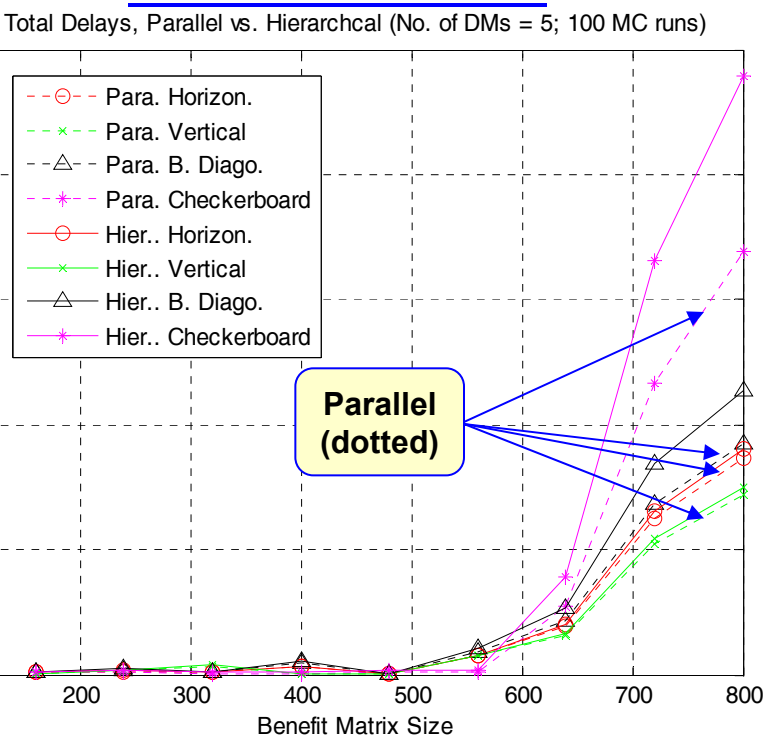
Distributed Auction Algorithms



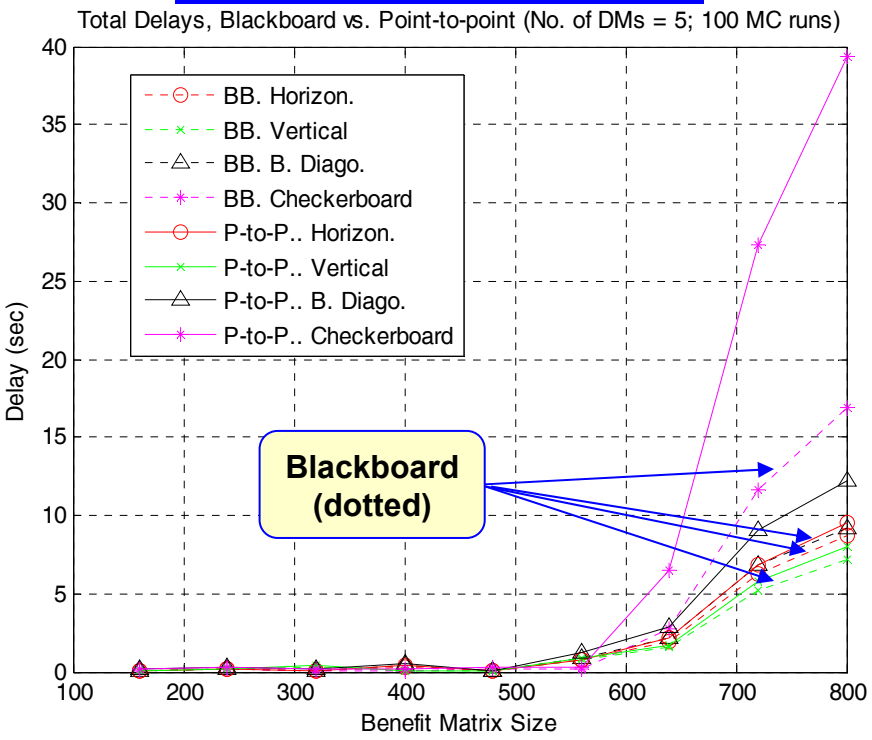
Performance of Distributed Auction Algorithm

Simulation Results (Delays) for Combination of Structures

Parallel vs. Hierarchical



Blackboard vs. Point-to-point



- Parallel structure is 1.1 ~ 1.5 times faster than Hierarchical tree structure
- Blackboard structure is 1.2 ~ 2.3 times faster than Point-to-point structure
- Horizontal/Vertical structures have better performance than other structures
- Checkerboard structure (akin to a matrix structure) shows the worst performance: Significant coordination delays and overlap among DMs
- Block diagonal structure shows reasonable performance: Coordinator resolves row-wise (divisional) & column wise (functional) conflicts
- Parallel structure with horizontal/vertical information structure is consistent with edge organizations

Summary and Future Work

Summary

- Distributed auction algorithms with various information ("who knows what"), communication ("who communicates with whom") and organizational ("who controls whom") structures
- By posting the bid, the best and the second best profits to the blackboard, the DMs can reconstruct the centralized assignment solution
- The performance of various information structures was evaluated by comparing the delays involved in converging to a centralized solution

Future Work

- Collaborative planning algorithms with partial information and partial control of assets
- Information and coordination structures to maximize organizational efficiency and be robust to a range of missions
- Multi-objective optimization techniques for resource allocation