Task Decomposition, Dynamic Role Assignment, and Low-bandwidth Communication for Real-time Strategic Teamwork

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Outline

- Background
- Periodic Team Synchronization (PTS)
- Team member agent architecture
- Locker-room agreements
  - Flexible teamwork structure
  - Communication protocol
- Implementation
  - Simulated robotic soccer
  - Results
- Conclusion and evaluation

Background

- A team of agents
- Agents negotiate and/or contract with each other.
- Problem:
  - In dynamic, real-time domains with limited communication, complex negotiation may take too much time and/or be infeasible.
- Time-critical environments alternating between:
  - Limited communication periods
  - Unlimited communication periods
- Periodic Team Synchronization (PTS)
  - Agents synchronize during the full-communication setting

PTS domains

- A team of autonomous agents *A*
- A joint long-term goal *G*

PTS domains

- Periodically, the team can synchronize with no restrictions on communication:
  - The agents can in effect inform each other of their entire internal states and decision-making mechanisms.
  - No adverse effects upon the achievement of G.
- "Off-line"

PTS domains

- In general, when the team is “on-line”:
  - The domain is dynamic and real-time, meaning that if an agent a_i ceases to act for a period of time, then:
    - G will be achieved with probability p' at time t with $p'<p$; or
    - G will be achieved with probability p at time t' with $t'>t$.
  - Unreliable communication:
    - A message m arrives with some probability $q < 1$; or
    - An agent a_i can only receive x messages every y time units.
- A cost to relying on communication
  - agents should act autonomously

Examples of PTS domains

- Robotic soccer:
  - Teams can plan strategies before the game, at halftime, or at other breakpoints
  - During the course of the game, all 22 agents use a single, low-bandwidth, unreliable communication channel.
- Other examples
  - Hospital/factory maintenance
  - Multi-spacecraft missions
  - Search and rescue
  - Battlefield combat

Approaches to PTS domains

- Locker-room agreements :
  - Pre-determined multi-agent protocols
  - Facilitate effective teamwork while remaining flexibility
- Team member agent architecture
  - Allows for an agent to act collaboratively based on the locker-room agreements
- Roles
  - Break the task into multiple roles
  - Assign one agent to each role
- Formations
  - A set of roles with associated behaviors
  - Homogeneous agents can switch roles within formations
  - Agents can change formations dynamically

Architecture overview

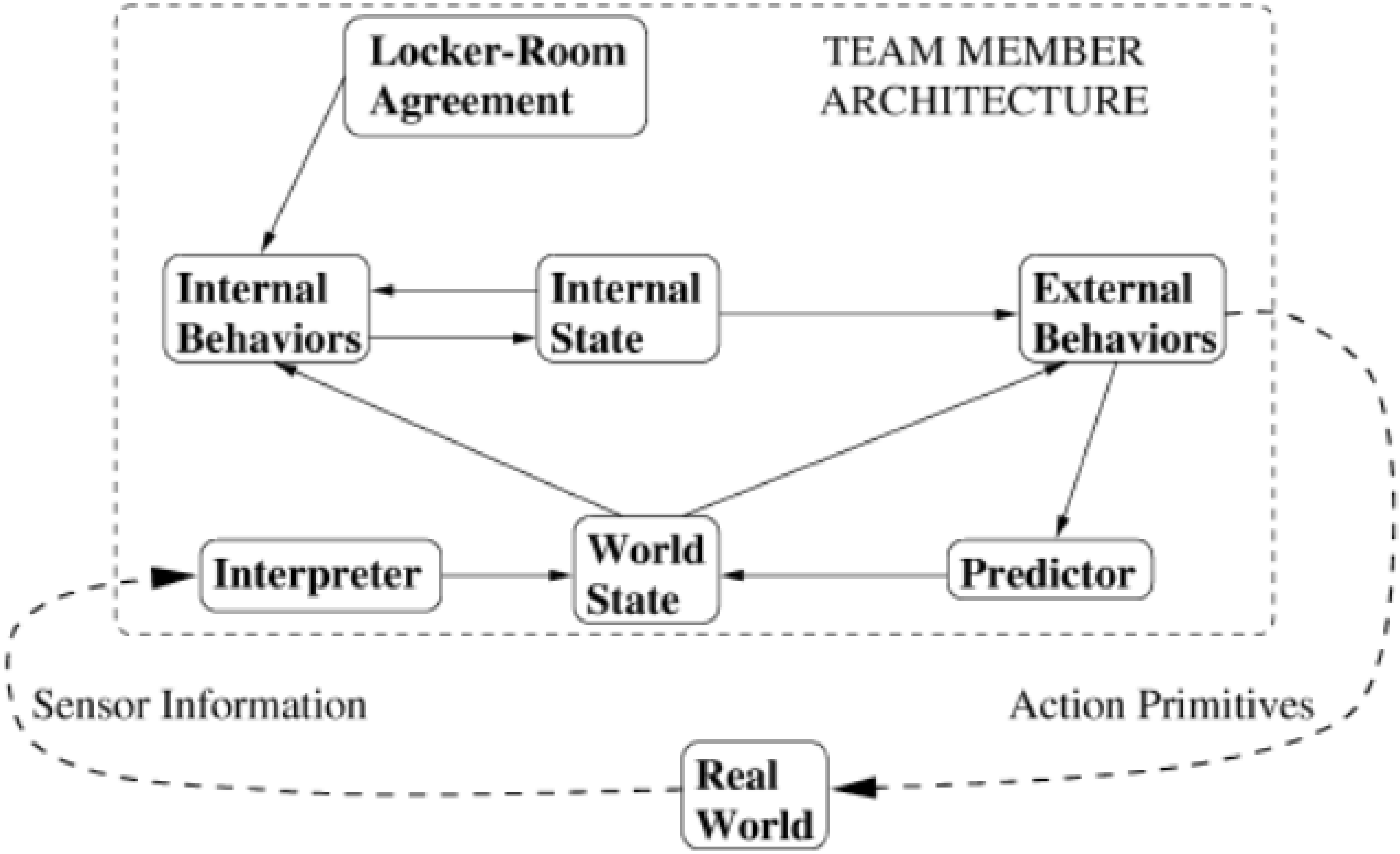

Fig. 1. A functional input/output model of the team member agent architecture for PTS domains.

Architecture overview

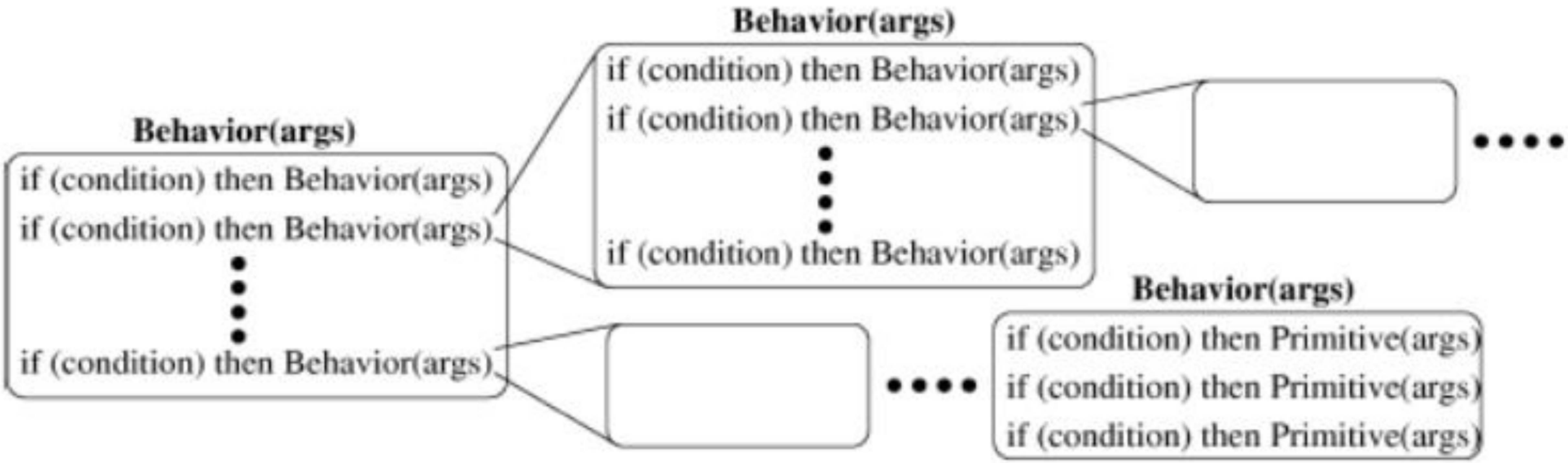

Fig. 2. Behaviors in the team member agent architecture. Both internal and external behaviors are organized as directed acyclic graphs.

Teamwork Structure

- Roles
  - A role consists of a specification of an agent’s internal and external behavior
  - Rigid vs. flexible

Teamwork Structure

- Formations
  - A formation decomposes the task space defining a set of roles
  - Formations can specify units
  - Roles and formations are independently from agents
  - Agents may have different perception of the team's formation.

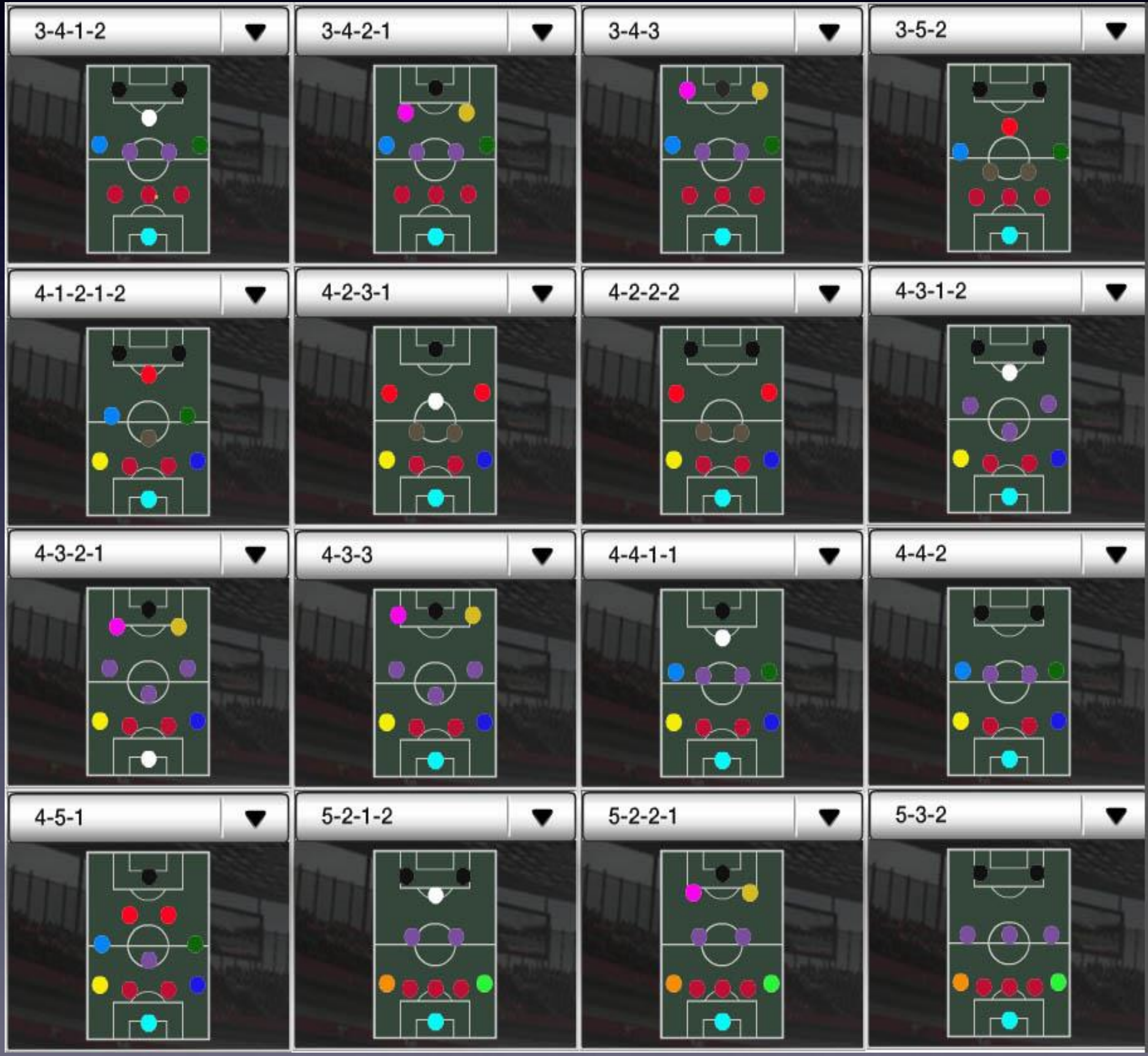

Figure 3. FIFA Ultimate Team Positions and Formations

Teamwork Structure

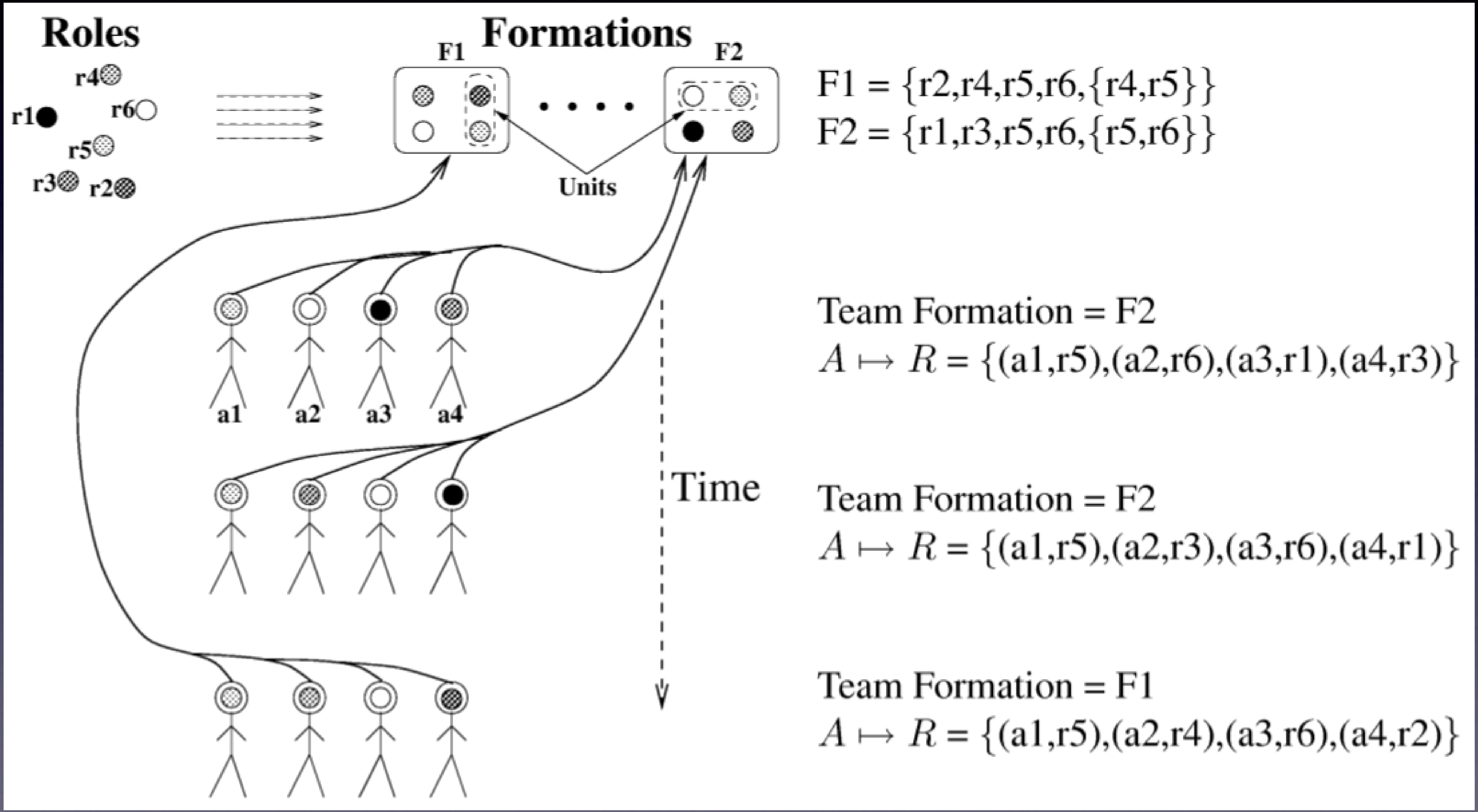

Figure 4. A team of agents smoothly switching roles and formations over time

Teamwork Structure

- Set-plays
  - Set-play is the combination of a trigger condition and a set of set-play roles
  - Each set-play role includes a set-play behavior and a termination

Communication Paradigm

- Five Challenges
  - Message targeting and distinguishing
  - Robustness to active interference
  - Multiple simultaneous responses
  - Robustness to lost messages
  - Team coordination

Communication Paradigm

- Message field
  - <team-identifier>
  - <unique-team-member-ID>
  - <encoded-time-stamp>
  - <time-stamped-team-strategy>
  - <selected-internal-state>
  - <message-type>
  - <target>

Communication Paradigm

- Message targeting and distinguishing
  - Agents hear all messages
  - Agents distinguish messages by checking the <team-identifier> and <target> field

Communication Paradigm

- Robustness to active interference
  - Encode the time-stamp
  - Message lag tolerance

Communication Paradigm

- Multiple simultaneous responses

Message target	Response request	
	No	Yes
Single agent	A1	B1
Whole team	A2	B2
Part of team	A3	B3

Communication Paradigm

- Robustness to lost messages
  - Agents continue to act while waiting for communicate-delay to expire
  - Agents maintain world and internal states independently

Communication Paradigm

- Team coordination
  - Via locker-room agreement
  - Via time stamp

Implementation in the robotic soccer domain

- Characteristics of the soccer server communication model
  - All 22 agents (including adversaries) on same channel
  - Limited communication range and capacity
  - No guarantee of sounds getting through
  - Instantaneous communication

Team structure implementation

Traditional task decomposition in the soccer server is to assign fixed positions to agents, which leads to several problems:

- Short-term inflexibility
- Long-term inflexibility
- Local inefficiency

Team structure implementation

External Behavior: Play Soccer()

If (Ball Lost)	Face Ball()
If (Ball known AND Chasing)	Handle Ball(args1)
If (Ball known AND Not Chasing)	Passive Offense(args2)
If (Communicate Flag Set)	Communicate()

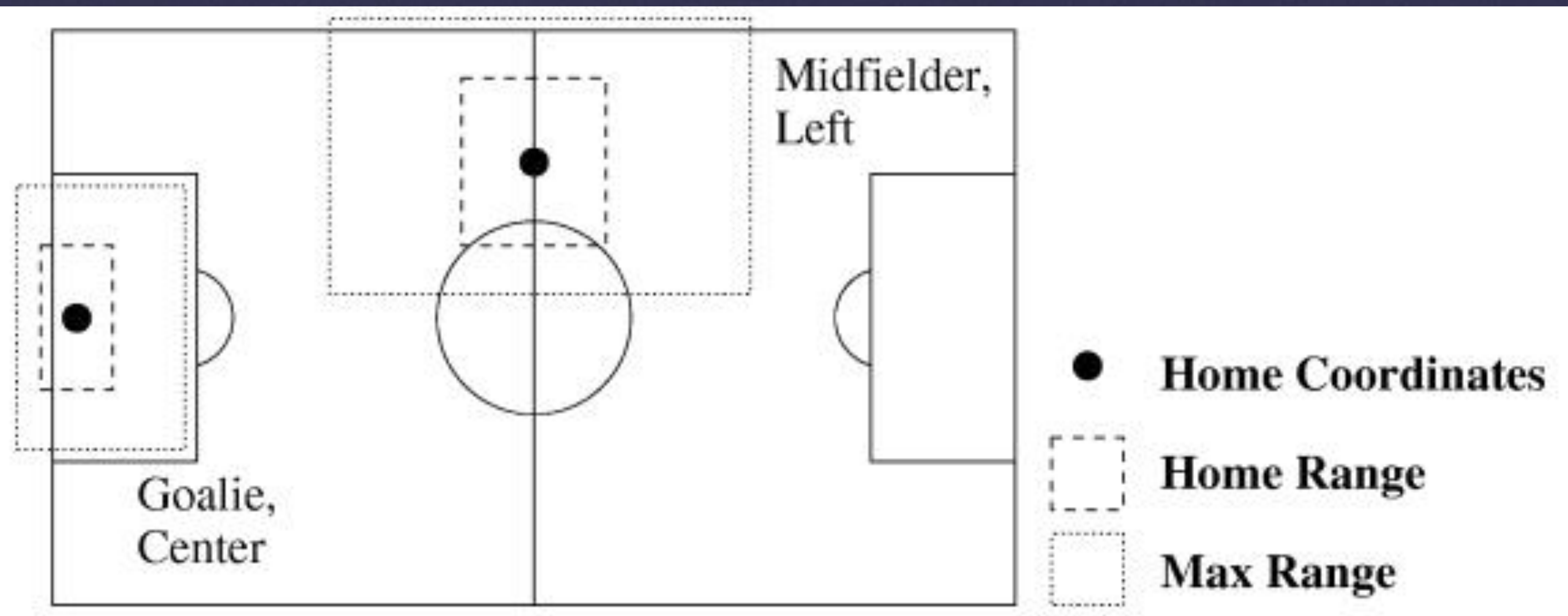

Fig. 5. Different positions with home coordinates and home and max ranges.

Team structure implementation

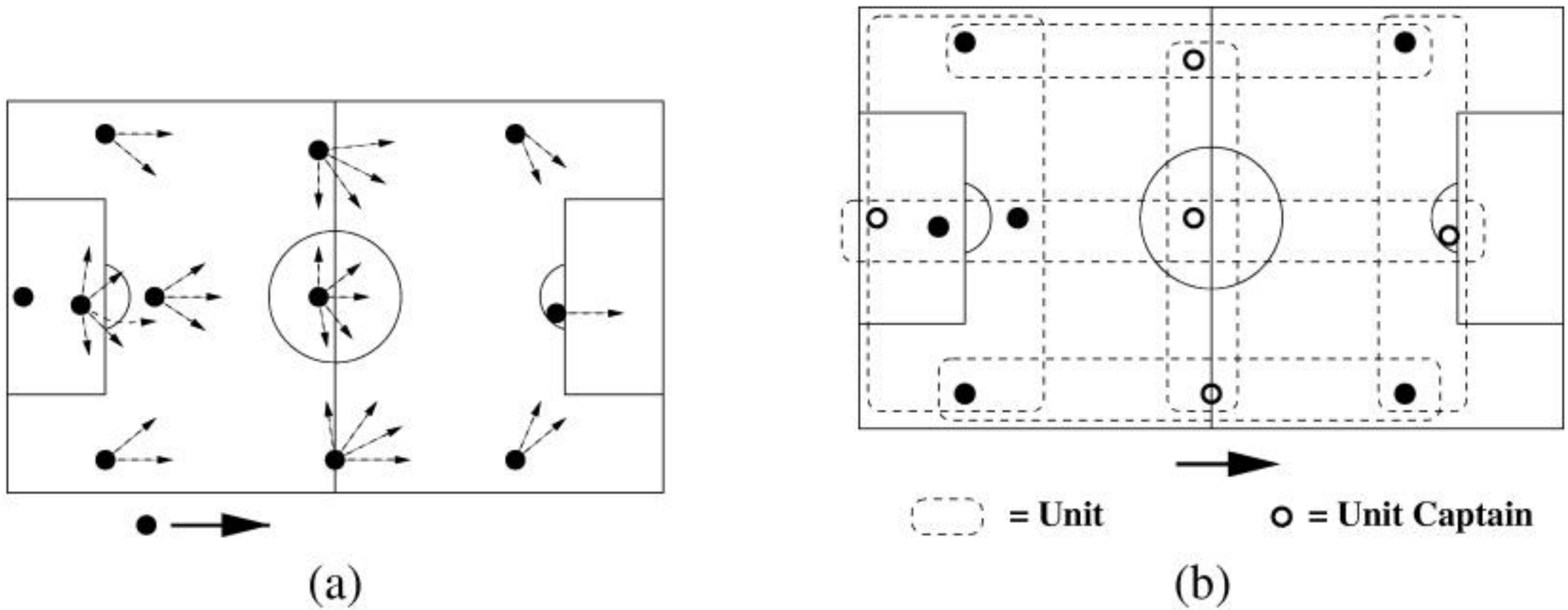

Fig. 6. (a) A possible formation (4-3-3) for a team of 11 players. Arrows represent passing options. (b) Positions can belong to more than one unit.

Team structure implementation

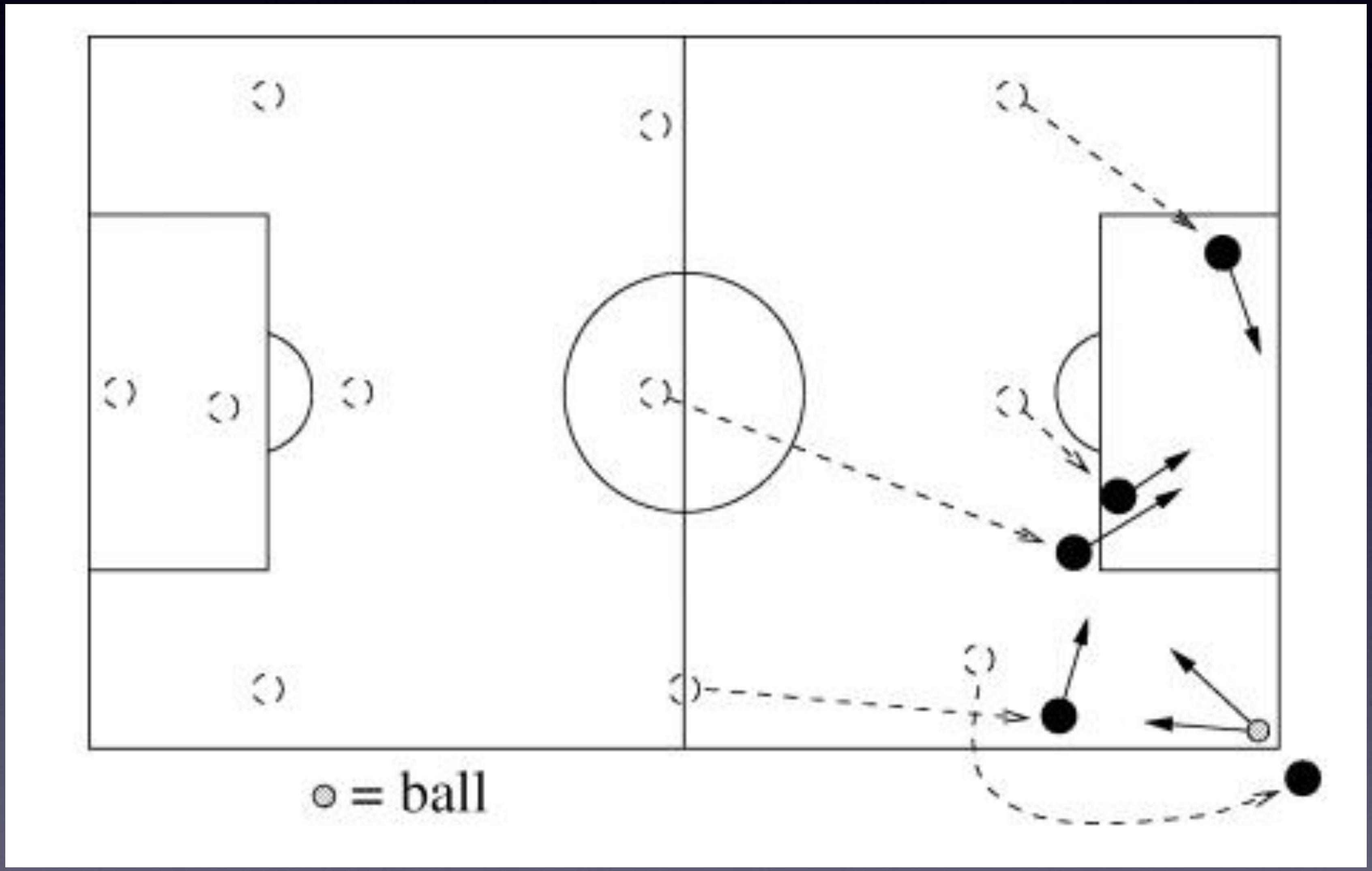

Figure 7. A sample corner-kick set-play

Results

Tearmwork structure results

Table 3
Results when a flexible team plays against a rigid team. The flexible team won 34 out of 38 games with 3 ties

(Game = 10 min.)	Flexible and set-plays	Default
Games won	34	1
Total goals	223	82
Avg. goals	5.87	2.16
Ball in own half	43.8%	56.2%

Teamwork structure results

Table 4
Results when only using flexible positions and only using set-plays. Each individually works better than using neither

Only flexible positions			Only set-plays		
(Game = 10 min.)	Flexible	Default	(Game = 10 min.)	Set-plays	Default
Games won	26	6	Games won	28	5
Total goals	157	87	Total goals	187	108
Avg. goals	4.13	2.29	Avg. goals	4.92	2.84
Ball in own half	44.1%	55.9%	Ball in own half	47.6%	52.4%

Formations

Table 5
Comparison of the different formations. Entries in the table show the number of goals scored. Total (and percentage) cumulative goals scored against all formations appear in the right-most column

Formations	4-3-3	4-4-2	3-5-2	8-2-0	3-3-4	2-4-4	Totals
4-3-3		68–60	68–54	24–28	59–64	70–65	289–271 (51.6%)
4-4-2	60–68		68–46	22–24	51–57	81–50	282–245 (53.5%)
3-5-2	54–68	46–68		13–32	61–72	75–73	249–313 (44.3%)
8-2-0	28–24	24–22	32–13		27–28	45–36	156–96 (61.9%)
3-3-4	64–59	57–51	72–61	28–27		87–69	308–267 (53.6%)
2-4-4	65–70	50–81	73–75	36–45	69–87		293–385 (43.2%)

Communication paradigm results

	Number of responses			Response time (sec)		
	Min	Max	Avg	Min	Max	Avg
No delay	1	1	1.0	0.0	0.0	0.0
Delay	6	9	8.1	0.0	2.6	0.9

Table 6. The number of responses that get through to agents when responses are delayed and when they are not.

	Entire team change time (sec)				Heard from
Decision-maker	Min	Max	Avg	Var	Decision-maker
Goaltender	0.0	23.8	3.4	17.8	46.6%
Midfielder	0.0	7.9	1.3	2.8	80.6%

Table 7. The time it takes for the entire team to change team strategies when a single agent makes the decision.

Conclusion

- **Introduce a flexible teamwork structure for PTS domains**

– Multi-agent tasks using homogeneous agents to be decomposed into flexible roles

– Roles are organized into formations, and agents can fill any role in any formation

– Pre-planning for frequent situations and agents act individually, but keep the team's goals in mind.

– Maintain both internal and world state, and internal and external behaviors.

– Coordination is achieved through limited communication and pre-determined procedures as a locker-room agreement.

- **A communication paradigm effective in domains with low bandwidth, single-channel, unreliable communication.**
- **A full implementation of our innovations in the simulated robotic soccer domain.**

Evaluations

- Team member agent architecture appropriate for PTS domain can be used in other scenarios
  - American football
  - NASA's multi-spacecraft missions
  - Search and rescue scenarios

- The synchronization problem in distributed planning becomes even greater when the distributed agents' plans are being executed concurrently

- Execution of plan is complicated by the presence of other agents, requiring not only methods for distributed plan execution but distributed plan repair.