Automated Negotiation for Supply Chain Management

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NEC-AIST AI Cooperative Research Laboratory

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The 7th IEEE International Conference on Agents

ICA 2023 Tutorial Updated on December 4, 2023

Outline

Why Now?

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1. Industries are moving online.
2. Automation: Factory floor $\rightarrow$ The back office.
3. Human-Human Negotiation is cumpersome, and inefficient.
4. Automated Negotiation opens new possiblities:
   - Too fast for people: Repeated smart contracts.
   - Too large for people: complete supply chains

Negotiation in SCM Business

- Human negotiations lead to an estimated 17-40% *value leakage* in some estimates [1]

[1] KPMG report: https://bit.ly/3kDRy6I
[2] Forrester report: https://bit.ly/3nwXEaY
[3] UN/CEFACT Project website: https://bit.ly/38LOsLX
[4] Y. Mohammad et al. "Supply Chain Management World: A benchmark environment for situated negotiations". In: *Proceedings of the 22nd International Conference on Principles and Practice of Multi-Agent Systems*. 2019.

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- A recent UNECE UN/CEFACT proposal to standardize negotiation protocols for SCM and other applications [3]
- More to come[4].

CONTRACTROOM

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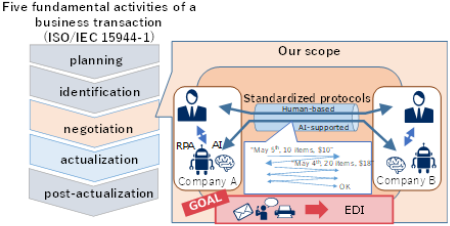
The Automated Negotiation Challenge

Why is it hard?

- Mechanism Design Problem:
  - Better than haggling?
- Negotiator Design Problem:
  - Generality $\times$ Effectiveness

Why is it interesting?

- Easy to state yet hard to solve.
- Multiple levels of abstraction and complexity.
- Several concrete open questions.
- Vibrant yet not saturated research space.



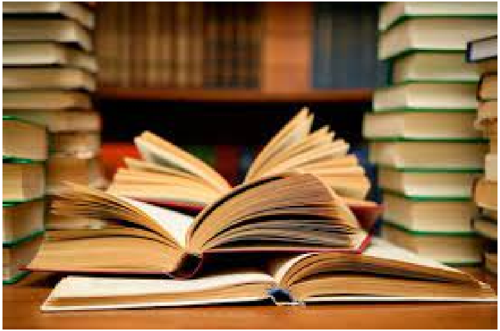
attribution: UNECE eNegotiation Project

Automated Negotiating Agents Competition: 2010-

Tutorial Outline

1. Theoretical Session (55min) Break (10min)
   - The Negotiation Problem (35min)
   - Automated Negotiating Agents Competition (ANAC) (5min)
   - Supply Chain Management League 15min
   - Anatomy of an Agent (10min)
2. Development Environment (50min) Break (10min)
   - Installing SCML (5min)
   - Running a simulation (5min)
   - Running Tournaments (5min)
   - Visualization and Logging (15min)
   - Troubleshooting and breathing time (10min)
3. Development Example (55min)
   - SCML Builtin Strategies (20min)
   - Example Agent Strategies (15min)
   - An RL based trading strategy (20min)
4. Conclusions (5min)

Materials



1. Tutorial Website: http://yasserm.com/tutorial-ica2023/
2. Github Repository: https://github.com/yasserfarouk/ica2023autoneg
3. Handouts: https://github.com/yasserfarouk/ica2023autoneg/raw/main/ica2023autoneg.pdf
4. Negmas Documentation: https://negmas.readthedocs.io
5. SCML Documentation: https://scml.readthedocs.io
6. SCML Competition: https://scml.cs.brown.edu

Outline

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1. Theoretical Session
   - The Negotiation Problem
   - Automated Negotiating Agents Competition: ANAC
   - Supply Chain Management League: SCML
2. Development Environment
3. Development Example

Outline

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1. Theoretical Session
   - The Negotiation Problem
     - Negotiation as a Game
     - Automated Negotiation Basics
     - Visualizing a Negotiation
   - Automated Negotiating Agents Competition: ANAC
   - Supply Chain Management League: SCML
2. Development Environment
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Types of Games

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Complete Information Game

- All game parameters are **common knowledge** except players' policies.
- All information sets has a single node.

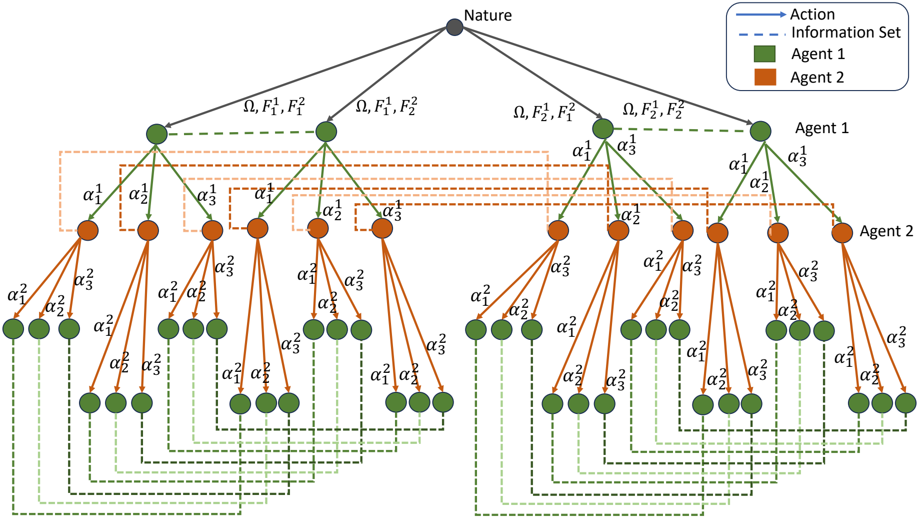
Imperfect Information Game

- Some partner infomration is unknown.
- Some information sets has multiple nodes.

Incomplete Information Game

- The game is not fully specified (e.g. unknown opponent ufun)
- Can be convereted to an Imprefect information game by adding **Nature** as a player.

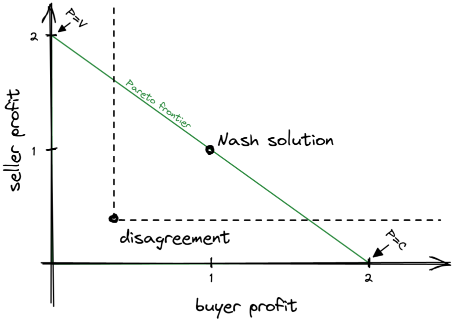
Induced Game with Incomplete Information



A Simple Trading Problem

- A buyer values a good at V
- A seller can create the good at cost C
- If $V > C$, then there is surplus $V - C$ to be gained (value creation)
- Bargaining problem: how much should the buyer pay the seller for the good? (value division)

- We might also assume there is an outside option (e.g., eBay), if the negotiation breaks down (i.e., they do not reach an agreement):
  - The buyer (seller) can buy (sell) the good elsewhere for slightly less than V (more than C)



Sketch by Jackson de Campos

No-go Theorem

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Desiderata:

- Efficient outcome.
- Individual rationality (IR).
- Incentive compatible (IC).
- Budget balance (BB).

Myerson-Satterthwaite Impossibility Result

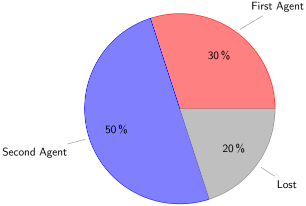
Theorem:[5] No mechanism can achieve all four of these desiderata.

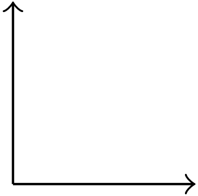
- A buyer values a good at V.
- A seller can create the good at cost C.
- V (C) is private information, known only to the buyer (seller).
- There is no IR, IC, and BB mechanism that results in agreement, for all $V > C$ values.

[5] Roger B Myerson and Mark A Satterthwaite. "Efficient mechanisms for bilateral trading". In: *Journal of economic theory* 29.2 (1983), pp. 265–281.

Nash Bargaining Game: Description

A single-step full-information bilateral negotiation with $\Omega = [0,1]^2$ and two utility functions $(\tilde{u}_1, \tilde{u}_2)$ such that:





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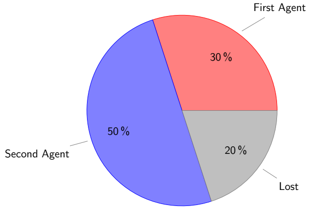
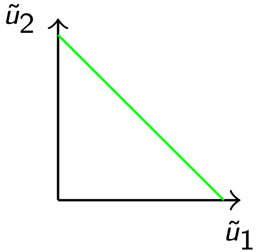
- A feasible set of agreements F. A common example is to define F as all the outcomes for which the total utility received by negotiators is less than or equal to one:

$$F = \{(\omega_1, \omega_2) | \tilde{u}_2(\omega_2) + \tilde{u}_1(\omega_1) \leq 1\}.$$





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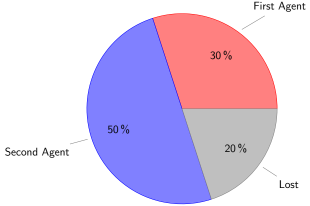

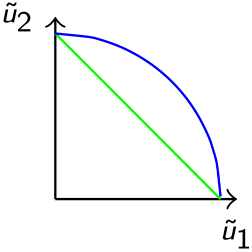

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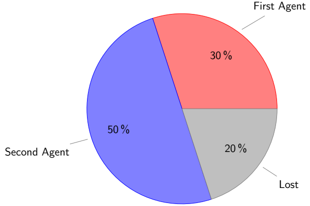

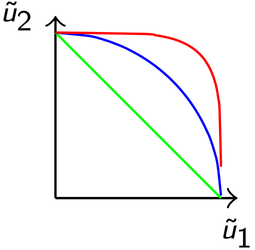

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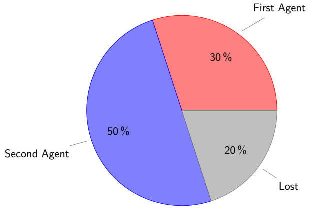
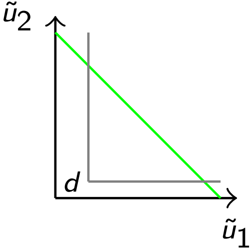
- A disagreement point $d \equiv \tilde{u}_1(\phi) + \tilde{u}_2(\phi) \in \Re^2$ which is the utility value received by the two players in case of disagreement (reserved values).





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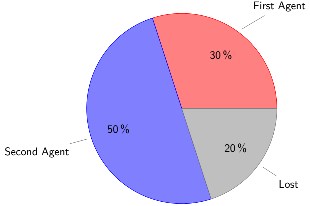

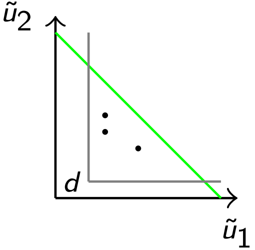

Other Bargaining Solutions

- Nash Bargaining Solution (1950): The point at which the product of surplus utility (above reservation value) of negotiators is maximized

$$\underset{\omega_1,\omega_2}{\arg\max} \prod_{i=1}^{2} \left(u_i(\omega_i) - u_i(\phi)\right)$$

- Kalai-Smorodinsky Bargaining Solution (1975): The Pareto outcome with equal ratios of achieved surplus utility and maximum feasible surplus utility

$$\underset{\omega_1,\omega_2 \in F}{\arg\max} \left(\omega_1 + \omega_2\right) \text{ s.t. } \left(\frac{u_1(\omega_1) - u_1(\phi)}{u_2(\omega_2) - u_2(\phi)} = \frac{\max_{v \in F}\left(u_1(v)\right) - u_1(\phi)}{\max_{v \in F}\left(u_2(v)\right) - u_2(\phi)}\right)$$

- Kalai Bargaining Solution (1977): The Pareto outcome maximizing the utility for the unfortunate player. Defining P as the Pareto front

$$\underset{\omega_1,\omega_2 \in P}{\arg\max} \; \min_{i \in \{1,2\}} \left(u_i(\omega_i) - u_i(\phi)\right)$$

Rubinstein's Bargaining Protocol: Description

The Game

- Two agents sharing a pie.

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- Each agent is under a different time-pressure: $u_i^{t+\Delta}(\omega) < u_i^t(\omega)$. Examples of time-pressure:

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Main Result

There is a unique *sub-game perfect equilibrium* that requires a single negotiation step in most cases.

Rubinstein's Bargaining Protocol: Equilibrium

Exponential Discounting

The negotiation ends in **one step** with the first agent proposing and the second agent accepting *for asymmetric cases*:

$$(\omega_1^*, \omega_2^*) = \left(\frac{1-\delta_2}{1-\delta_1\delta_2}, \frac{\delta_2\left(1-\delta_1\right)}{1-\delta_1\delta_2} \right)$$

Rubinstein's Bargaining Protocol: Equilibrium

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Linear Discounting

The negotiation ends in **one step** with the first agent proposing and the second agent accepting:

$$(\omega_1^*, \omega_2^*) = \begin{cases} (c_2, 1-c_2) & c_1 > c_2 \\ (x, 1-x)\ \forall x \in [c_1, 1] & c_1 = c_2 \\ (1, 0) & c_1 < c_2 \end{cases}$$

Negotiation with Complete Information

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Hick's Paradox

Why do rational parties negotiate when they have full information?

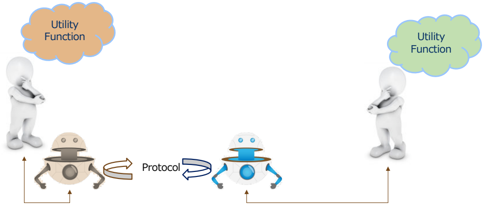
Labor vs. Management

- A union negotiating (in rounds) with management about a wage raise.
- Both parties are perfectly rational and fully informed.
- Threat: the union *can* strike.

Theorem[6] Subgame perfect equilibria exist in which there is a finite strike followed by agreement.

[6] Raquel Fernandez and Jacob Glazer. *Striking for a bargain between two completely informed agents.* Tech. rep. National Bureau of Economic Research, 1989.

Components of Negotiation



Negotiation Scenario Defines who is negotiating about what

Negotiation Protocol Defines how negotiation is to be conducted

- Alternating Offers Protocol
- Single Text Protocol
- . . .

Negotiation Strategy Defines how agents behave during a negotiation

- Time-based strategies: boulware, conceder, . . .
- Tit-for-tat variations
- . . .

Notation

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Negotiation Scenario $\mathcal{S}$

Agent Indices $\mathcal{A}^{\mathcal{S}}$: The set of n_A agents.

Domain $\mathcal{D}^{\mathcal{S}}$: A tuple $(K, \mathcal{F}^{\mathcal{S}})$ defining the situation:

- **Outcome Space K:** A set of all possible agreements with $\phi \notin K$ representing disagreement. $K^+ \equiv K \bigcup \{\phi\}$ is called the Extended Outcome Space.
- **Preferences Tuple $\mathcal{F}^{\mathcal{S}}$:** A tuple of n_A members that defines the preferences of each agent engaged in the negotiation.
- **Information Set Tuple $\mathcal{I}^{\mathcal{S}}$:** A tuple of n_A information sets $\left(\left\{\mathrm{I}_f^{\mathcal{S}}(\mathcal{F}^{\mathcal{S}}) \mid f \in \mathcal{A}^{\mathcal{S}}\right\}\right)$ where $\mathrm{I}_f^{\mathcal{S}}(\mathcal{F}^{\mathcal{S}})$ represents all the information available to agent x about the preferences $\mathcal{F}^{\mathcal{S}}$ of all agents including itself.

Protocol $\mathcal{P}$: The negotiation protocol.

Negotiation Protocol Execution: $\mathcal{P}(\mathcal{S})$

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Protocol

Breaking Rule when the negotiation ends with a timeout.

Action Constraints **what** actions are valid.

Activation Rule **which** each agent is activated.

Evaluation Rule the next step:

- Continue ▷ Goto breaking rule.
- Agreement Succeed with ω.
- Disagreement Fail with ϕ.

Agent (Strategy)

Selects an action from the **valid action set**.

Algorithm 1 Negotiation Mechanism Execution: $\mathcal{P}_{\Upsilon}(\lambda)$

Input: Scenario $\lambda \equiv \left(\mathcal{N}^{\lambda}, \left(\Omega, \mathcal{F}^{\lambda}\right), \mathcal{I}^{\lambda} \equiv \left\{\mathrm{I}_x^{\lambda} : x \in \mathcal{N}^{\lambda}\right\}\right)$, Mechanism $\mathcal{P}_{\Upsilon} = (\mathcal{P}, \Upsilon) : \mathcal{P} = (\zeta, \chi, \sigma)$

Output: $\omega_* \in \Omega \cup \{\phi\}$

```
x ≈ π_x ∀x ∈ N^λ ← Υ(λ)                         ▷ Assign strategies
i, t, t_0, T ← 0, 0, clock(), ⟨⟩                 ▷ Init step, time and trace
while ζ(T, i, t; λ) = 0 do                        ▷ check the breaking rule
    N_i^λ, ← χ(T, i; λ)                           ▷ Next active agents
    for x ∈ N_i^λ do                              ▷ Activate agents
        A_x^v ← γ(T, x; λ)                        ▷ Valid action set
        α_i^x ← π_x (T, A_x^v; I_x^λ)             ▷ Receive action
        T ← T + ⟨α_i^x, x⟩                        ▷ Update the trace
        z ← σ (T, i; λ)                           ▷ Evaluation rule
        if z = φ then return φ                    ▷ End with disagreement
        else if z ∈ Ω then return ω_i             ▷ agreement
        end if                                    ▷ Otherwise continue to the next step
    end for
    i, t ← i + 1, clock() − t_0                   ▷ Update step and time.
end while
return φ                                          ▷ Disagreement on breaking rule returning 1
```

Visualizing a negotiation

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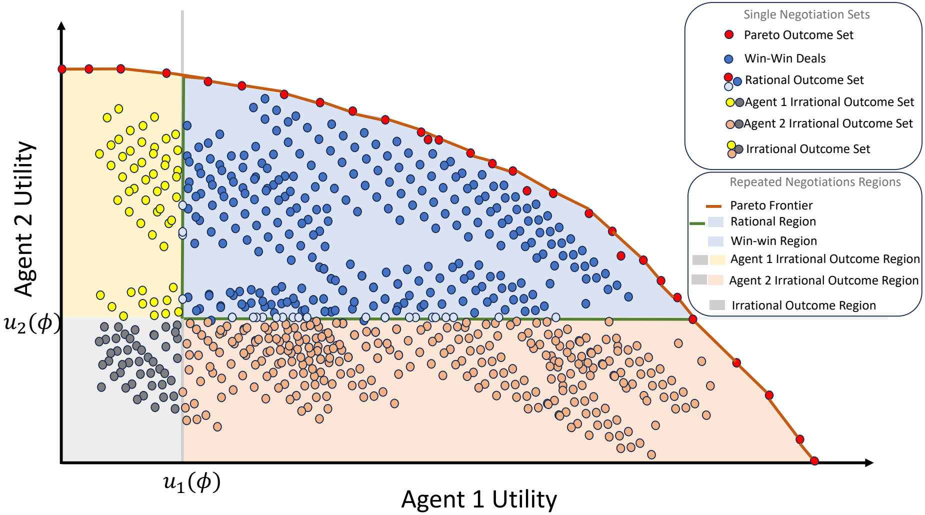

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Automated Negotiating Agents Competition (ANAC)

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- An international competition dedicated to automated negotiation.
- Started in conjunction with AAMAS in 2010.
- Running every year with AAMAS or IJCAI (14 iterations so far).
- Next ANAC will be in conjunction with AAMAS 2024 (not official yet).

Outline

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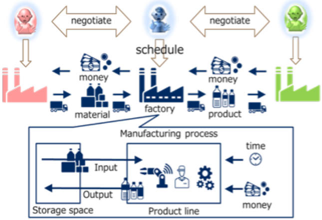
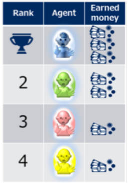
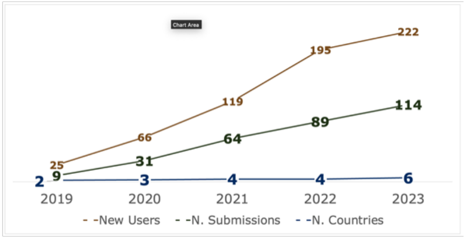
Supply Chain Management League (SCML)

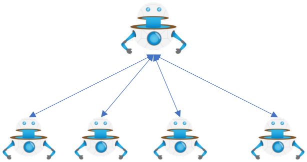
- Running as part of ANAC since 2019.
- **Scenario** A market in which all trade is done through concurrent closed bilateral negotiations:
  - Represents several applications in the real world.
- Agent preferences are endogenous to the simulation.
- **Goal** Maximize your profit.
- **Main Challenges**:
  - Situated Negotiations.
  - Sequential Negotiation (learning between negotiations).
  - Concurrent Negotiation (outside-options).
  - Trust management.







Concurrent Negotiation

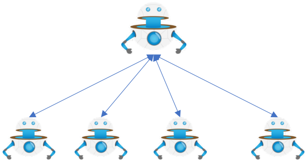


Concurrent Negotiation

NEC-AIST AI Cooperative Research Laboratory

Generality

- Specific scenario (buyer-seller).
- General domain



Concurrent Negotiation

NEC-AIST AI Cooperative Research Laboratory

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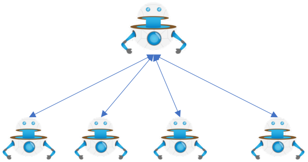
Decommitment

- Symmetric de-commitment.
- Asymmetric de-commitment.
- No de-commitment.



Concurrent Negotiation

Generality

- Specific scenario (buyer-seller).
- General domain

Decommitment

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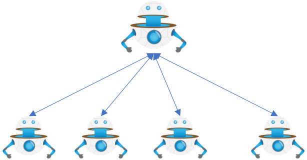
- Asymmetric de-commitment.
- No de-commitment.

Timing

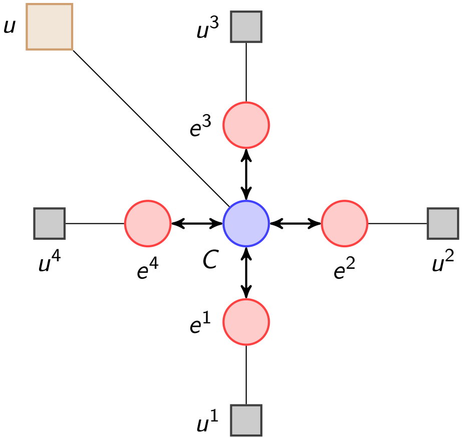
- Synchronous.
- Any-time.



Concurrent Negotiations

These negotiations are dependent, as evidenced by the global ufun u, which depends on a global outcome: i.e., the outcomes of all negotiations.

The problem of how to negotiate in this setting is reminiscent of how to bid in simultaneous auctions, when bidders' utilities are combinatorial.[7]

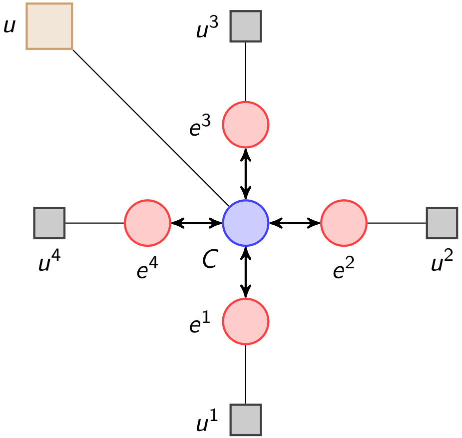


[7] Michael P. Wellman, Eric Sodomka, and Amy Greenwald. "Self-confirming price-prediction strategies for simultaneous one-shot auctions". In: *Games and Economic Behavior* 201 (2017), pp. 339–372.

Concurrent Negotiations

In ANAC SCML, an agent negotiates with multiple agents simultaneously. Moreover, the agent's utility depends on the outcomes of all the negotiations.

An agent represents a factory, whose production depends on the inputs it acquires from all its trading partners, and so, in turn, does its sales.



SCML World

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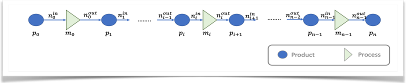
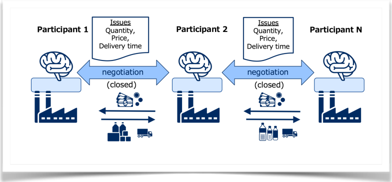
Challenge

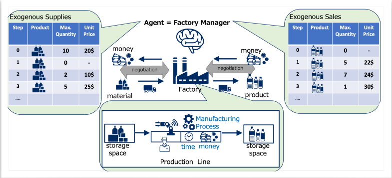
- Negotiation game with imperfect information
- Concurrent negotiations.
- Repeated negotiations → OneShot.
- Sequential negotiations → Standard.

Information

- **Website** https://scml.cs.brown.edu/
- **Code** https://www.github.com/yasserfarouk/scml







SCML Competition

NEC-AIST AI Cooperative Research Laboratory

Competition Details

- Runs as part of ANAC IJCAI.
- You control one or more factories.
    - **Oneshot track** → one factory (predefined ufun).
    - **Standard track** → one factory (you define your own ufun).
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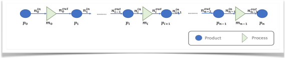
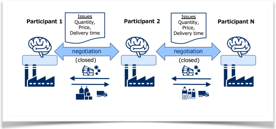
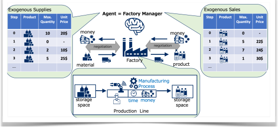
Flavors

- Online competition at https://scml.cs.brown.edu
- Official competition as part of ANAC.







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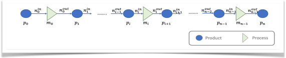
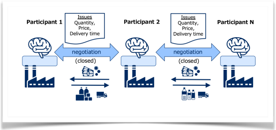
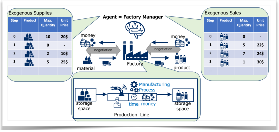
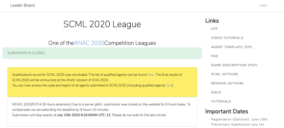
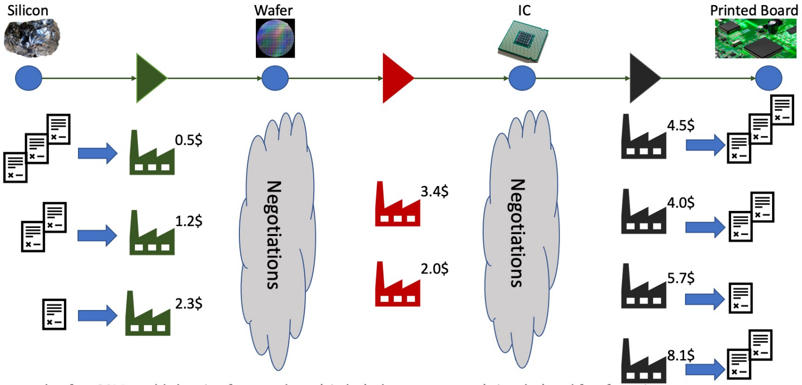






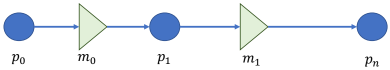


Example Configuration



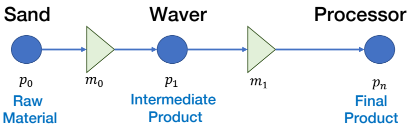
An example of an SCM world showing four products (circles), three processes (triangles) and few factories.
Each process consumes one item of its input and generates one output of its output in one day.
Each factory requires a different cost to run its process (shown in its top right).
Factories in the first level have exogenous contracts to buy raw material (silicon) and factories at the last level have exogenous contracts to sell the final product (printed boards). These contracts drive the market.

Overview



- A **production-graph** defines what can be produced and how.

Overview



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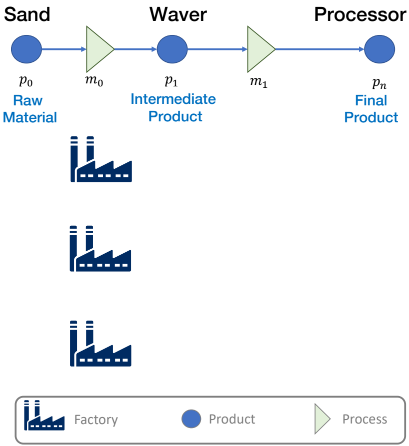

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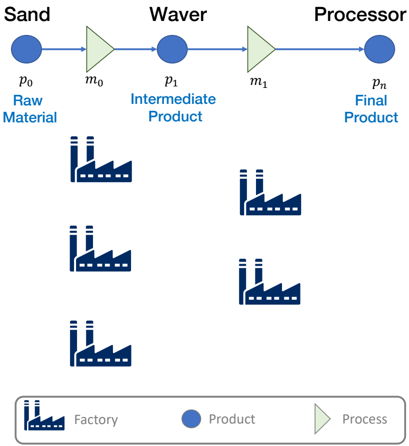

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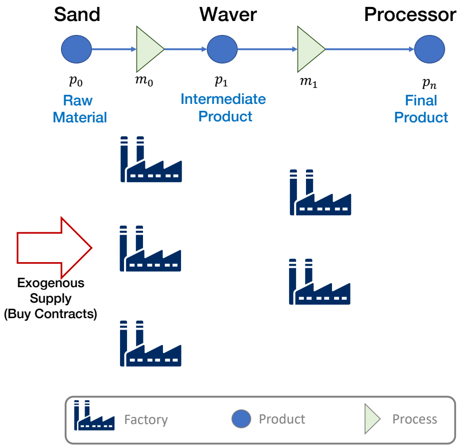

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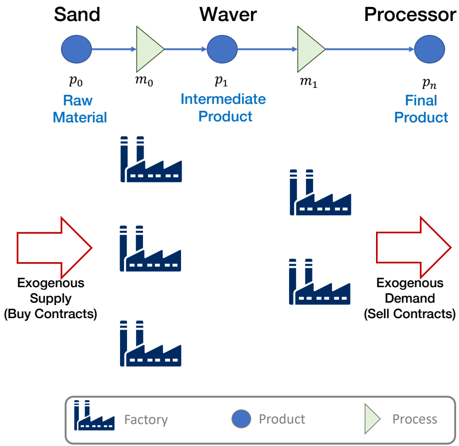

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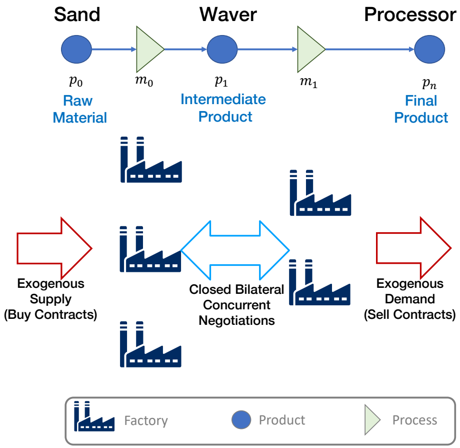
Overview

NEC-AIST AI Cooperative Research Laboratory



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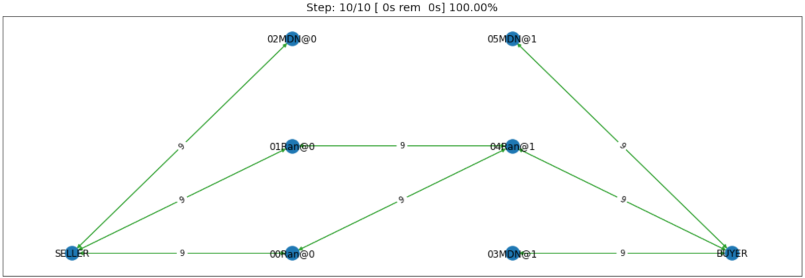
- We have two layers of factories/agents.
- L_0 factories/agents receive exogenous supplies of raw material.
- L_1 factories/agents receive exogenous sales of final product.
- L_0 negotiate with L_1 agents to exchange intermediate product

SCML-OneShot Track



Main Idea

- Agents arranged in two production levels (3 products, 2 processes)
- Every day you get a fresh set of exogenous contracts.
- All products perish in one day (no inventory accomulation).

Utility Function

General Form

Utility = Profit = Sales - Supply cost - Production cost - Disposal cost - Delivery Penalty

Sales unit price $\times$ quantity $\forall$ feasible sales.

Supply cost unit price $\times$ quantity $\forall$ supplies.

Production cost unit production cost $\times$ quantity produced.

Disposal cost unit disposal cost $\times$ quantity bought but not produced.

Shortfall penalty unit shortfall penalty $\times$ infeasible sales.

Information about self

NEC-AIST AI Cooperative Research Laboratory

Static Information

- Number of production lines.
- Production cost.
- Mean and variance of disposal cost and shortfall penalty.
- Input/output product, consumers/suppliers, n. input/output negotiations.

Dynamic Information

- current input/output negotiation issues.
- current input/output exogenous contracts (quantity, unit price).
- current disposal cost and shortfall penalty.
- Current balance (money in wallet).

Market Information

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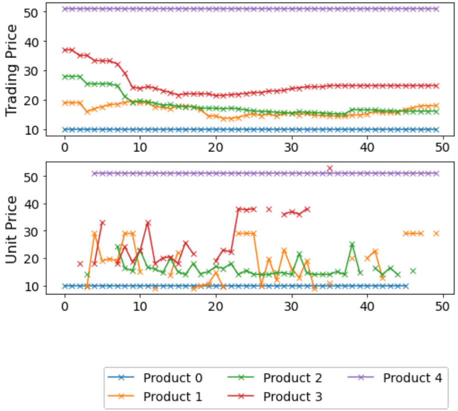
Trading prices

- Trading prices represent a weighted running average of different product prices.
- Available to the agent through the AWI in all tracks.

Exogenous Contract Summary

- The total quantity and average prices of all exogenous contracts are now available through the AWI.
    - Exogenous contracts for individual agents are private information.



Other Agents' Information

Financial Reports

For each agent, a financial report is published every m days (e.g. 5) with the following information:

- Current balance (money in wallet).
- breach probability (fraction of sale contracts not satisfied).
- breach level (average fraction of sales not satisfied).

Simulation Steps

Once

Initialize all agents

- init()

Simulation Steps

Once

Initialize all agents

- init()

Update trading prices

Simulation Steps

NEC-AIST AI Cooperative Research Laboratory

Once

- Initialize all agents
  - init()
- Update trading prices
- Create exogenous contracts and sample agent's disposal cost, and shortfall penalty

Simulation Steps

NEC-AIST AI Cooperative Research Laboratory

Once

- Initialize all agents
  - init()

Every

- Update trading prices
- Create exogenous contracts and sample agent’s disposal cost, and shortfall penalty
- Initialize agents for the day
  - before_step() [First call every day]

Simulation Steps

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Every Day

- Update trading prices
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  - propose() respond() | on_neg*_success() on_neg*_failure()

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- Finalize agents for the day
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NEC-AIST AI Cooperative Research Laboratory

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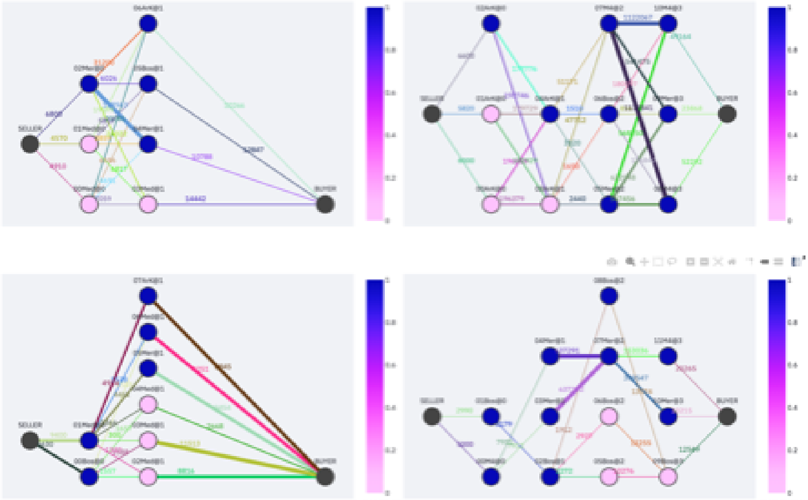
  - step() [Last call every day]
- Publish Financial Reports

SCML Environment



Outline

NEC-AIST AI Cooperative Research Laboratory

1. Theoretical Session
2. Development Environment
   - Installing SCML
   - Running a simulation
   - Running a tournament
   - Visualization and logging
   - Troubleshooting and breathing time
   - NegMAS: The Underlying Platform
3. Development Example

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Installing SCML

NEC-AIST AI Cooperative Research Laboratory

Pre-Installation

```
> python3 -m venv .venv
> source .venv/bin/activate
> .venv\\Scripts\\activate
```

Basic Installation

```
> pip install scml
```

Optional Installations

```
> pip install scml-agents
> pip install scml-vis
```

Outline

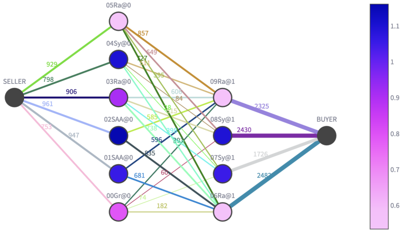
Running a single simulation (oneshot)

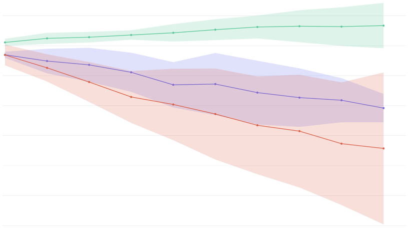
Command Line Tool

```
> scml run2024 --oneshot
```

Python

```
SCML2024OneShotWorld(
**SCML2024OneShotWorld.generate(
agent_types=DefaultAgentsOneShot2024
)).run()
```





Running a single simulation (std)

Command Line Tool

```
> scml run2024
```

Python

```
SCML2024StdWorld(
**SCML2024StdWorld.generate(
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)).run()
```
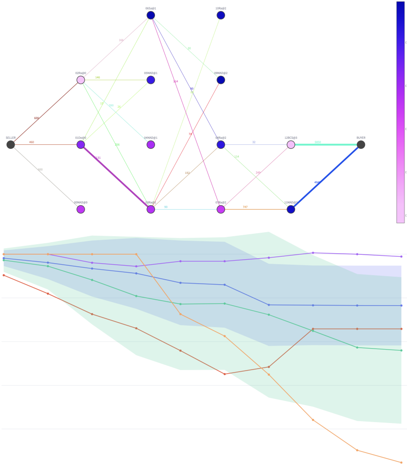



Outline

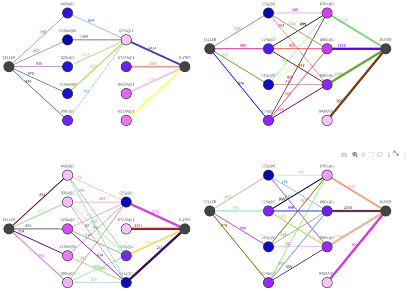
Running a complete tournament (oneshot)

Command Line Tool

```
> scml tournament2024 --type=oneshot
```

Python

```
anac2024_oneshot(
    competitors=[
        RandomOneShotAgent,
        SyncRandomOneShotAgent,
        GreedyOneShotAgent
])
```



Running a complete tournament (std)

NEC-AIST AI Cooperative Research Laboratory

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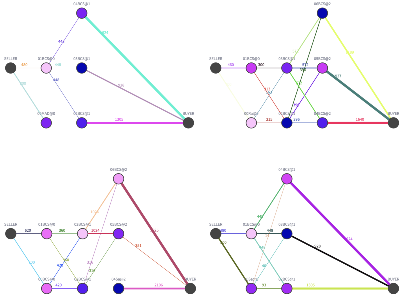

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Visualization CLI

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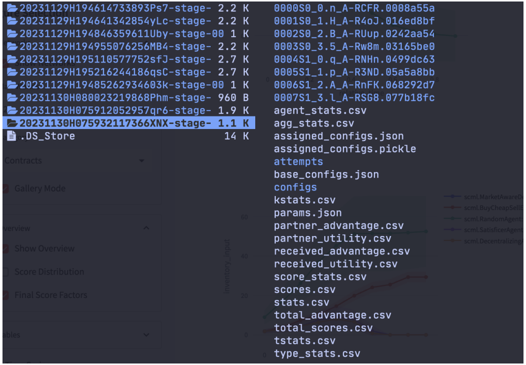
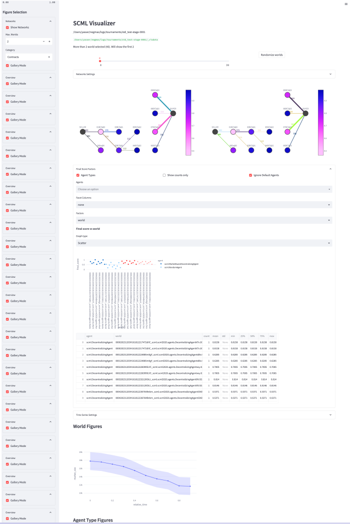
Command Line Tool

> scmlv show





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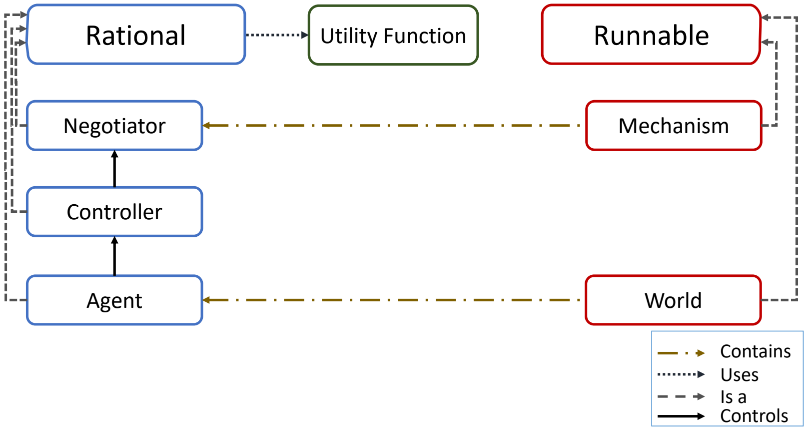
Troubleshooting and breathing time

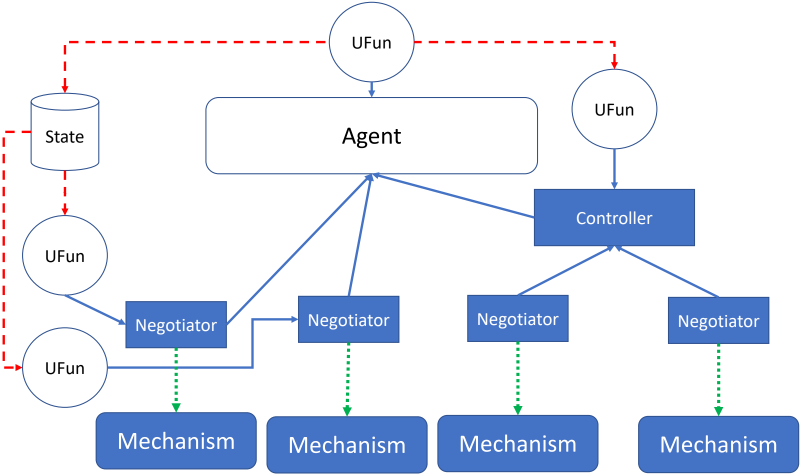
Outline

NegMAS[7] in two slides

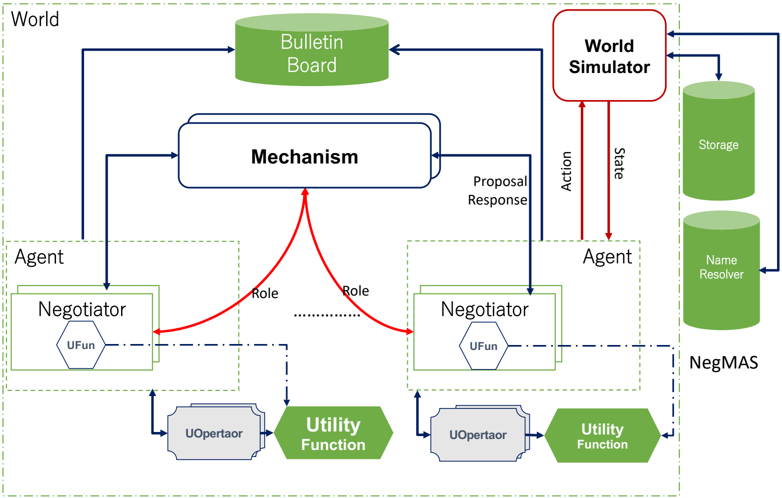


[7] https://www.github.com/yasserfarouk/negmas

NegMAS in two slides



NegMAS in two slides (... OK 3)



NegMAS in two slides (... really!!!)

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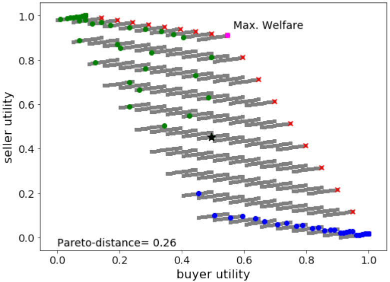

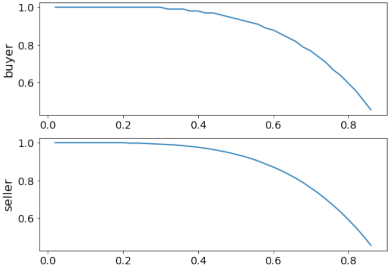

- An Example negotiation.
- Can you spot a problem?

Outline

Outline

NEC-AIST AI Cooperative Research Laboratory

SCML-OneShot Agent: Core

```
class OneShotSyncAgent(SAOSyncController, OneShotAgent, ABC):
    """
    An agent that automatically accumulate offers from opponents and allows
    you to control all negotiations centrally in the `counter_all` method.

    Args:
+---  4 lines: owner: The adapter owning the agent. You do not need to directly deal···

    """

    def __init__(self, *args, **kwargs):
+---  2 lines: kwargs["global_ufun"] = True·····································

    @abstractmethod
    def counter_all(
        self, offers: dict[str, Outcome], states: dict[str, SAOState]
    ) -> dict[str, SAOResponse]:
+--- 20 lines: """Calculate a response to all offers from all negotiators··············

    @abstractmethod
    def first_proposals(self) -> dict[str, Outcome]:
+--- 10 lines: """·······························································
```

SCML-OneShot Agent: Optional Timing Callbacks

```
    def init(self):
---   6 lines: """...............................................
     |
    def before_step(self):
---   8 lines: """...............................................
     |
    def step(self):
---   8 lines: """...............................................
     |
```

SCML-OneShot Agent: Optional Events

```
    def on_negotiation_failure(
---  5 lines: self,·····································
    ) -> None:
--- 12 lines: """·······································

    def on_negotiation_success(
        self, contract: Contract, mechanism: NegotiatorMechanismInterface
    ) -> None:
---  8 lines: """·······································
```

Outline

Greedy Random Agent

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jupyter

- Link to builtin agent examples (OneShot)
- Link to builtin agent examples (Std)

Outline

Example Winner Agents

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- Link to 2023 winner agent descriptions
- Link to source code and description of every agent

Outline

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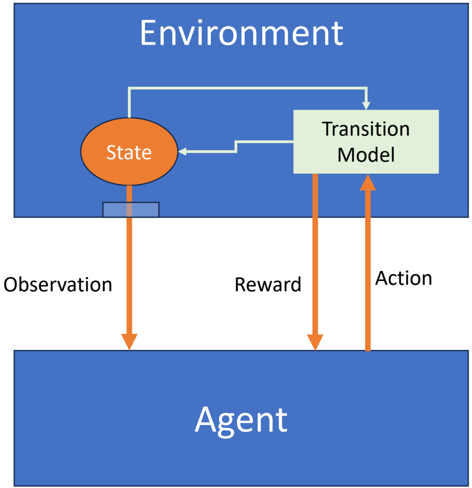
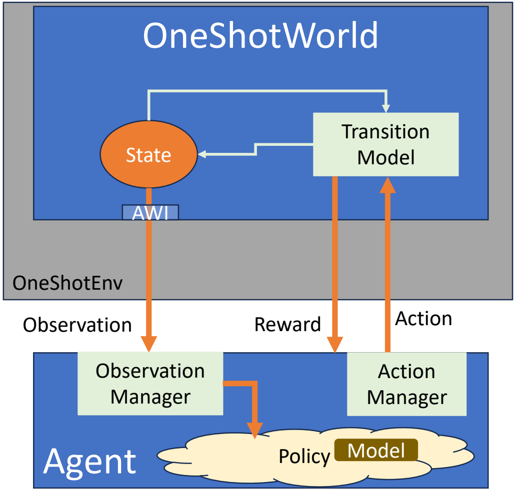
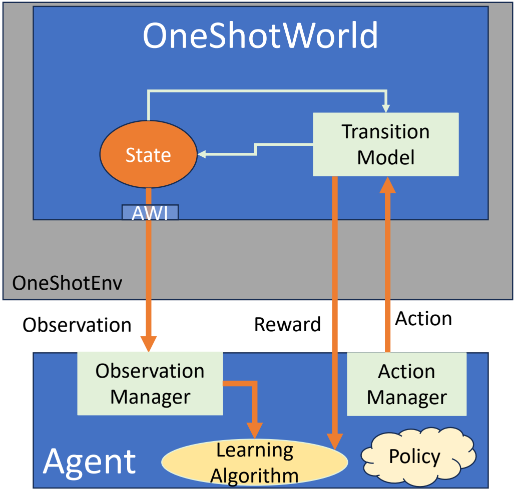
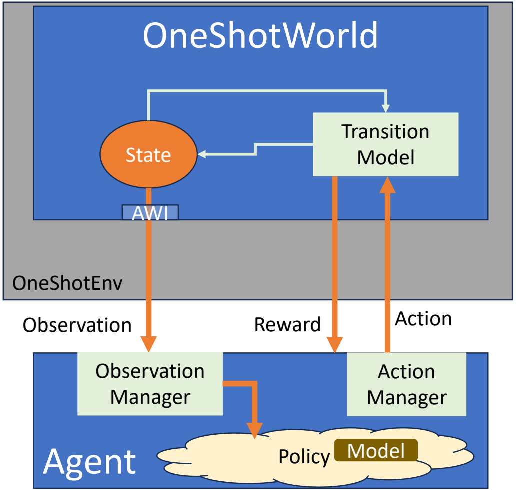
RL for SCML


Environment
State
Transition
Model
Observation
Reward
Action
Agent


OneShotWorld
State
Transition
Model
AWI
OneShotEnv
Observation
Reward
Action
Observation
Manager
Action
Manager
Agent
Policy
Model

RL for SCML


OneShotWorld
Transition Model
State
AWI
OneShotEnv
Observation
Reward
Action
Observation Manager
Action Manager
Agent
Learning Algorithm
Policy


OneShotWorld
Transition Model
State
AWI
OneShotEnv
Observation
Reward
Action
Observation Manager
Action Manager
Agent
Policy
Model

RL for SCML: Main Challenges

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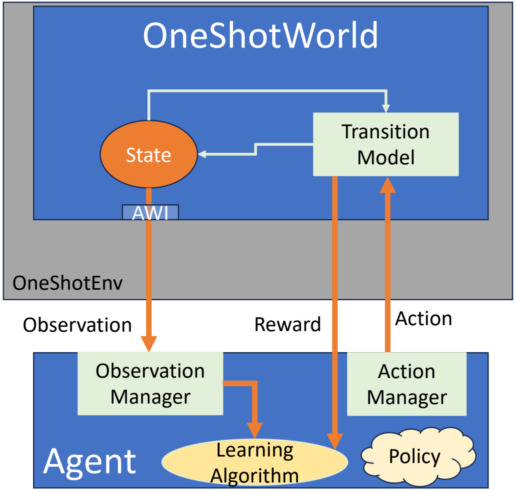
- Huge and hybrid observation space
  - The main challenge is to design a good ObservationManager
- Sparse Reward
  - Does Reward Shaping help?
  - Can we devise a reward signal other than the profit (e.g. KPIs)?
- Every simulation is different (i.e. competitors, suppliers, consumers).
  - How to handle variable number of negotiations (i.e. elastic action space)?
  - How to negotiations ending at different time (in the same day)?
  - How to divide all possible simulations into usable contexts suitable for learning?
- How to learn (learning algorithm)?



Developing and RL agent for SCML: training

Developing and RL agent for SCML: testing

Outline

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References I

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