

Automated Negotiation for Supply Chain Management

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ICA 2023 Tutorial Updated on December 4, 2023

Outline

- ① Theoretical Session
- ② Development Environment
- ③ Development Example

Why Now?

- ① Industries are moving online.
- ② Automation: Factory floor → The back office.
- ③ Human-Human Negotiation is cumbersome, and inefficient.
- ④ Automated Negotiation opens new possibilities:
 - 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

¹KPMG report: <https://bit.ly/3kDRy6l>

²Forrester report: <https://bit.ly/3nwXEaY>

³UN/CEFACT Project website: <https://bit.ly/38LOsLX>

⁴Y. 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

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- A recent UNECE UN/CEFACT proposal to standardize negotiation protocols for SCM and other applications ³
- More to come⁴.

CONTRACTROOM

pactum

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The Automated Negotiation Challenge

Why is it hard?

- Mechanism Design Problem:
 - Better than haggling?
- Negotiator Design Problem:
 - Generality × 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.

Five fundamental activities of a business transaction (ISO/IEC 15944-1)



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)

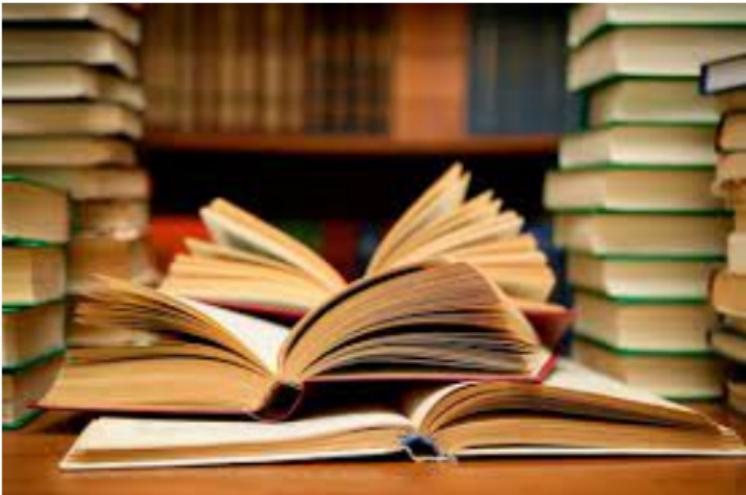
- Installing SCML (5min)
- Running a simulation (5min)
- Running Tournaments (5min)
- Visualization and Logging (15min)
- Troubleshooting and breathing time (10min)

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

1 Theoretical Session

- The Negotiation Problem
- Automated Negotiating Agents Competition: ANAC
- Supply Chain Management League: SCML
- Anatomy of an Agent

2 Development Environment

3 Development Example

Outline

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
- Anatomy of an Agent

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Types of Games

Complete Information Game

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

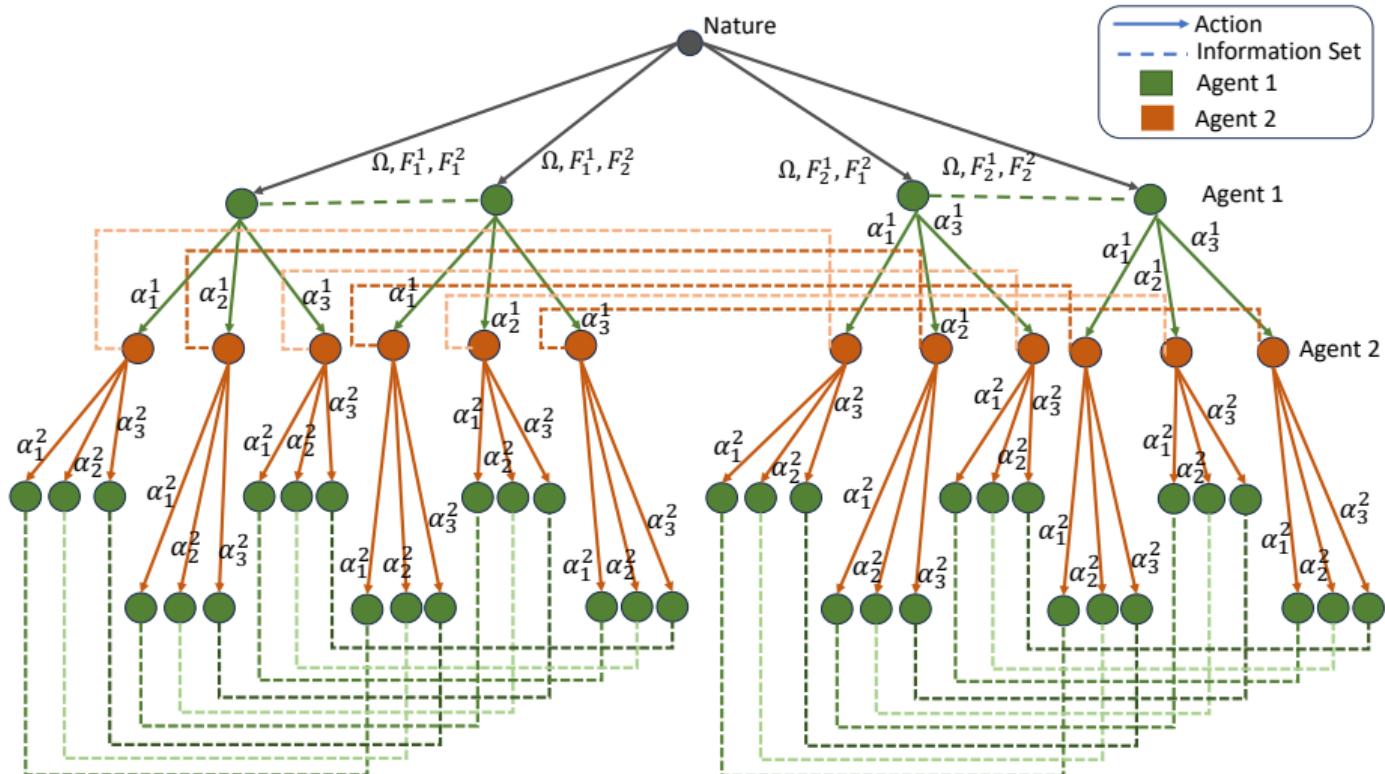
Imperfect Information Game

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

Incomplete Information Game

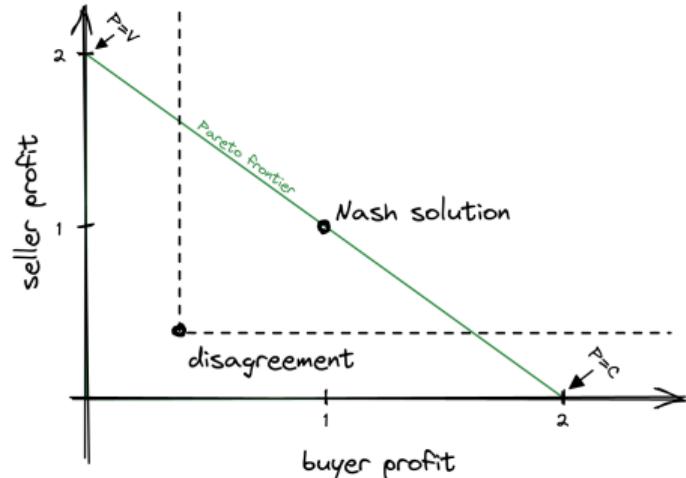
- The game is not fully specified (e.g. unknown opponent ufun)
- Can be converted to an Imperfect information game by adding **Nature** as a player.

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

Desiderata:

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

Myerson-Satterthwaite Impossibility Result

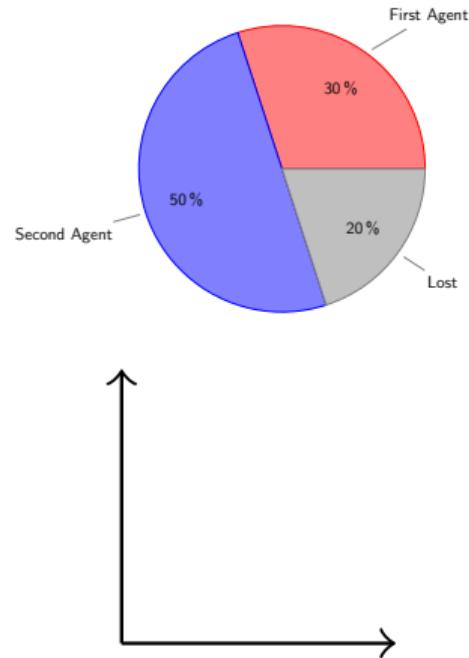
Theorem:⁵ No mechanism can achieve all four of these desiderata.

- 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.

⁵Roger 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:

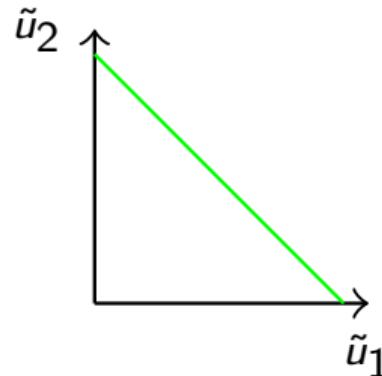
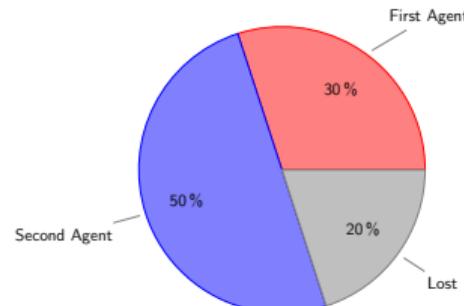


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- A feasible set of agreements F . A common example is to define F as all the outcomes for which the total utility received by negotiators is less than or equal to one:

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

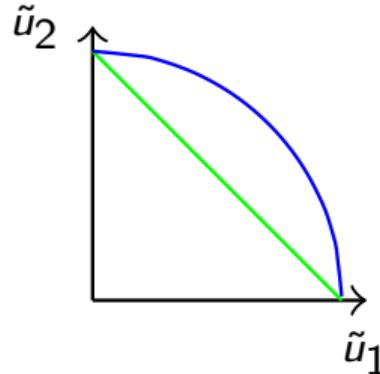
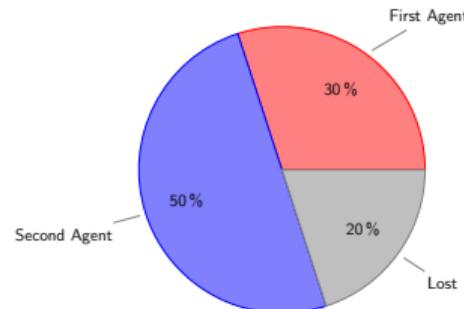


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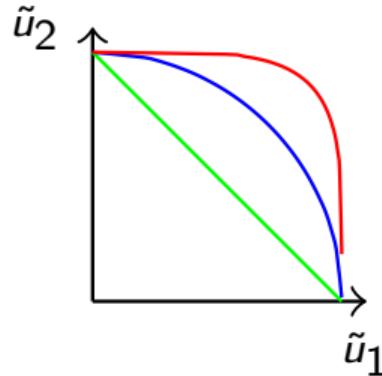
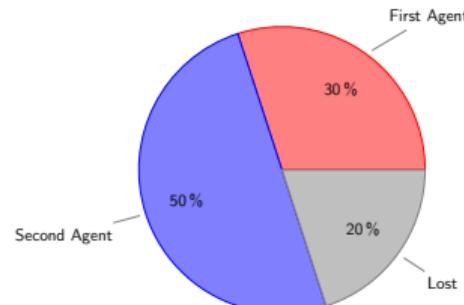


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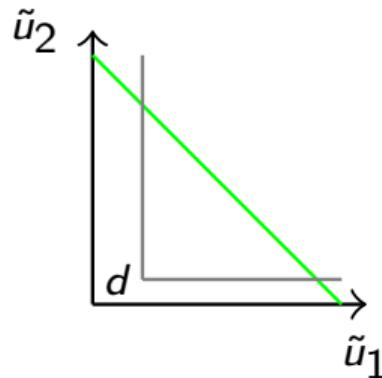
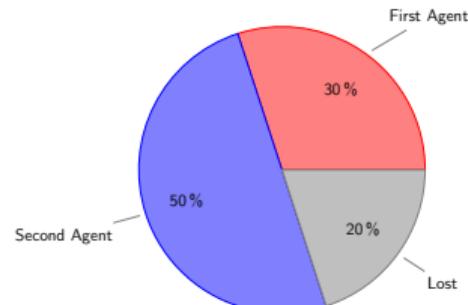
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- A disagreement point $d \equiv \tilde{u}_1(\phi) + \tilde{u}_2(\phi) \in \Re^2$ which is the utility value received by the two players in case of disagreement (reserved values).



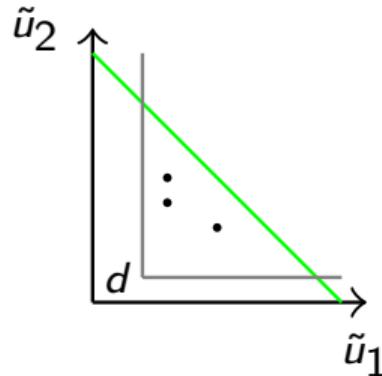
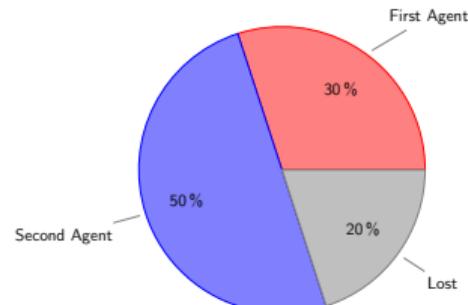
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Other Bargaining Solutions

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

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

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

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

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

$$\arg \max_{\omega_1, \omega_2 \in P} \min_{i \in \{1,2\}} (u_i(\omega_i) - u_i(\phi))$$

Rubinstein's Bargaining Protocol: Description

The Game

- Two agents sharing a pie.

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Linear $u_i^{t+\Delta}(\omega) = u_i^t(\omega) - \Delta c_i$

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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*:

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

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:

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

Negotiation with Complete Information

Hick's Paradox

Why do rational parties negotiate when they have full information?

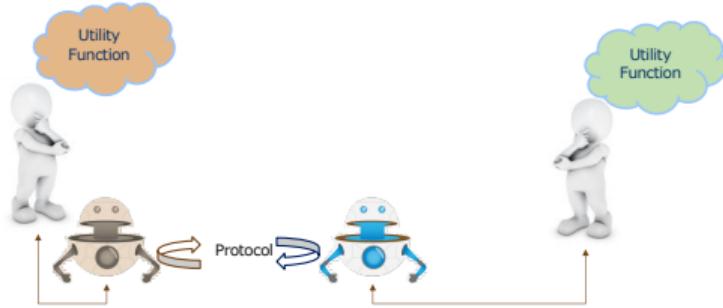
Labor vs. Management

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

Theorem⁶ Subgame perfect equilibria exist in which there is a finite strike followed by agreement.

⁶Raquel 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

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. $K^+ \equiv K \cup \{\phi\}$ 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 $(\{I_f^{\mathcal{S}}(\mathcal{F}^{\mathcal{S}}) \mid f \in \mathcal{A}^{\mathcal{S}}\})$ where $I_f^{\mathcal{S}}(\mathcal{F}^{\mathcal{S}})$ 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: $\mathcal{P}(\mathcal{S})$

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: $\mathcal{P}_Y(\lambda)$

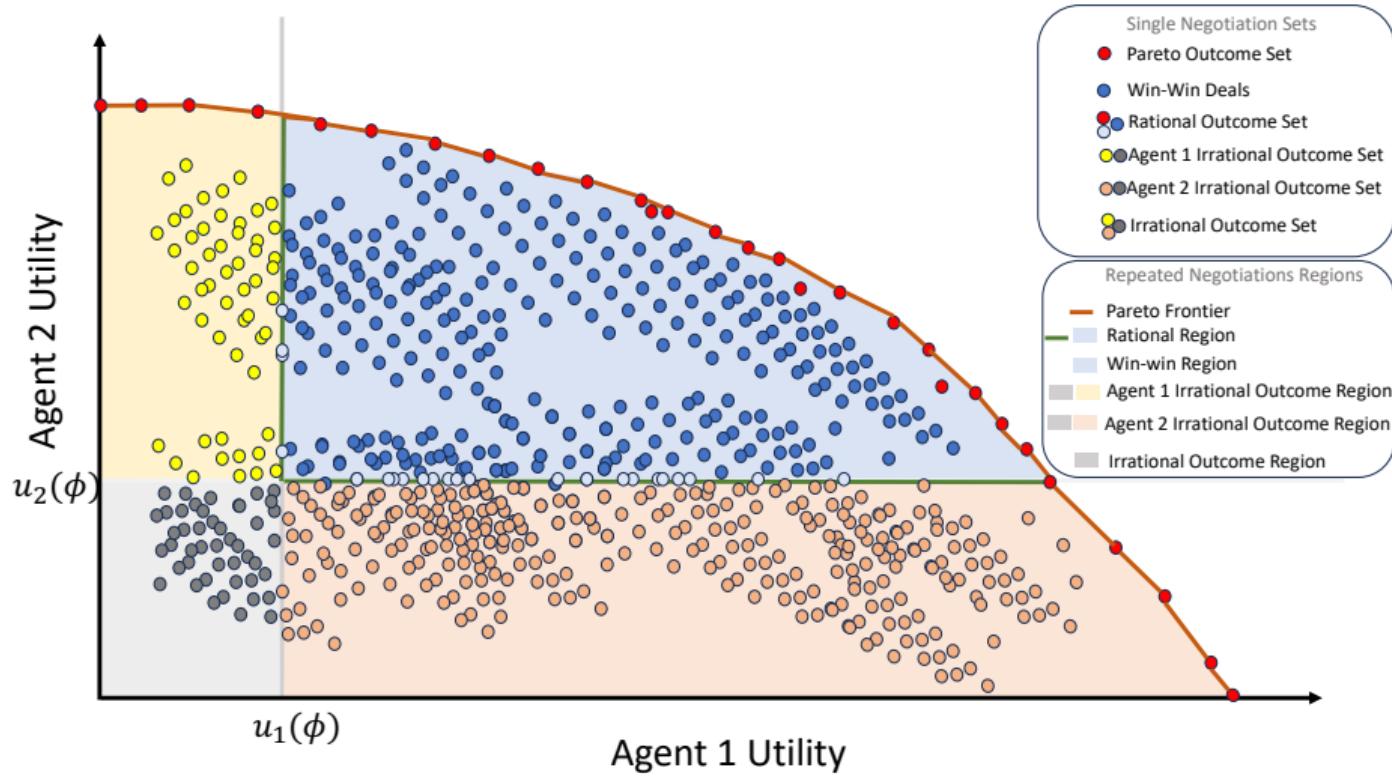
Input: Scenario $\lambda \equiv (\mathcal{N}^\lambda, (\Omega, \mathcal{F}^\lambda), \mathcal{I}^\lambda \equiv \{I_x^\lambda : x \in \mathcal{N}^\lambda\})$,
 Mechanism $\mathcal{P}_Y = (\mathcal{P}, Y) : \mathcal{P} = (\zeta, \chi, \sigma)$

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

```

1:  $x \approx \pi_x \forall x \in \mathcal{N}^\lambda \leftarrow Y(\lambda)$                                 ▷ Assign strategies
2:  $i, t, t_0, \mathcal{T} \leftarrow 0, 0, \text{clock}(), \langle \rangle$                             ▷ Init step, time and trace
3: while  $\zeta(\mathcal{T}, i, t; \lambda) = 0$  do                                         ▷ check the breaking rule
4:    $\mathcal{N}_i^\lambda \leftarrow \chi(\mathcal{T}, i; \lambda)$                                          ▷ Next active agents
5:   for  $x \in \mathcal{N}_i^\lambda$  do                                              ▷ Activate agents
6:      $\mathbb{A}_x^v \leftarrow \gamma(\mathcal{T}, x; \lambda)$                                          ▷ Valid action set
7:      $\alpha_i^x \leftarrow \pi_x(\mathcal{T}, \mathbb{A}_x^v; I_x^\lambda)$                                ▷ Receive action
8:      $\mathcal{T} \leftarrow \mathcal{T} + \langle \alpha_i^x, x \rangle$                                      ▷ Update the trace
9:      $z \leftarrow \sigma(\mathcal{T}, i; \lambda)$                                          ▷ Evaluation rule
10:    if  $z = \phi$  then return  $\phi$  ▷ End with disagreement
11:    else if  $z \in \Omega$  then return  $\omega_i$                                          ▷ agreement
12:    end if                                         ▷ Otherwise continue to the next step
13:  end for
14:   $i, t \leftarrow i + 1, \text{clock}() - t_0$                                          ▷ Update step and time.
15: end while
16: return  $\phi$                                          ▷ Disagreement on breaking rule returning 1
  
```

Visualizing a negotiation



Outline

1 Theoretical Session

- The Negotiation Problem
- **Automated Negotiating Agents Competition: ANAC**
- Supply Chain Management League: SCML
- Anatomy of an Agent

2 Development Environment

3 Development Example

Automated Negotiating Agents Competition (ANAC)

- 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

1 Theoretical Session

- The Negotiation Problem
- Automated Negotiating Agents Competition: ANAC
- Supply Chain Management League: SCML
 - SCML-OneShot
 - Simulation Steps
- Anatomy of an Agent

2 Development Environment

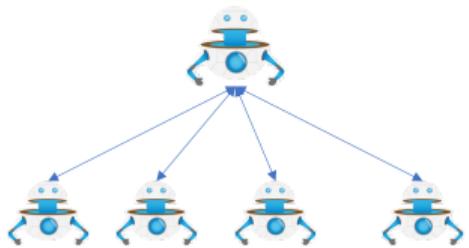
3 Development Example

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.



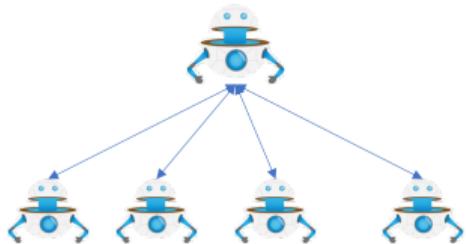
Concurrent Negotiation



Concurrent Negotiation

Generality

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



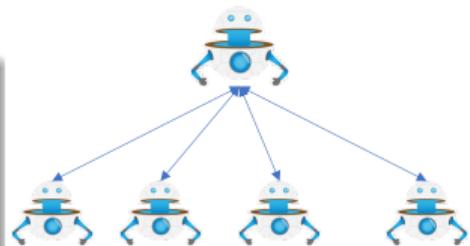
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Decommitment

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



Concurrent Negotiation

Generality

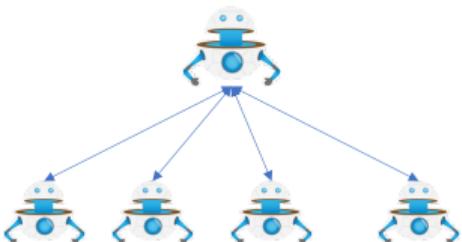
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Timing

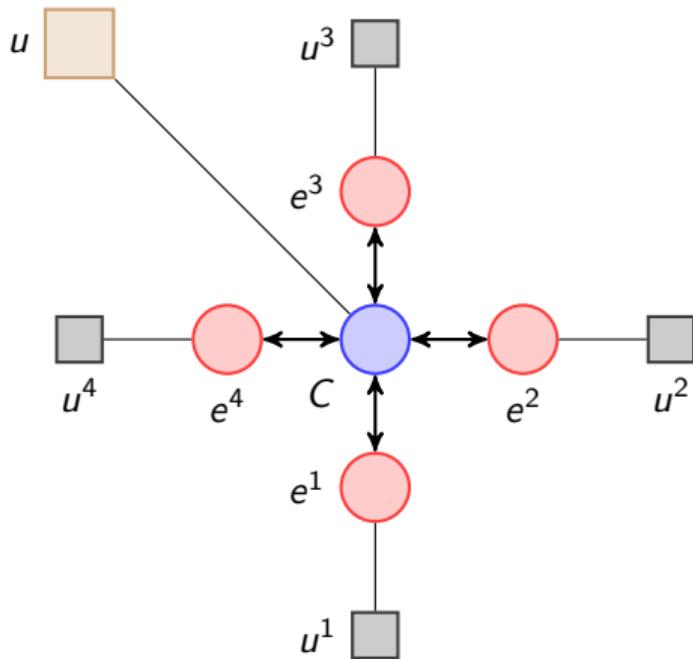
- Synchronous.
- Any-time.



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

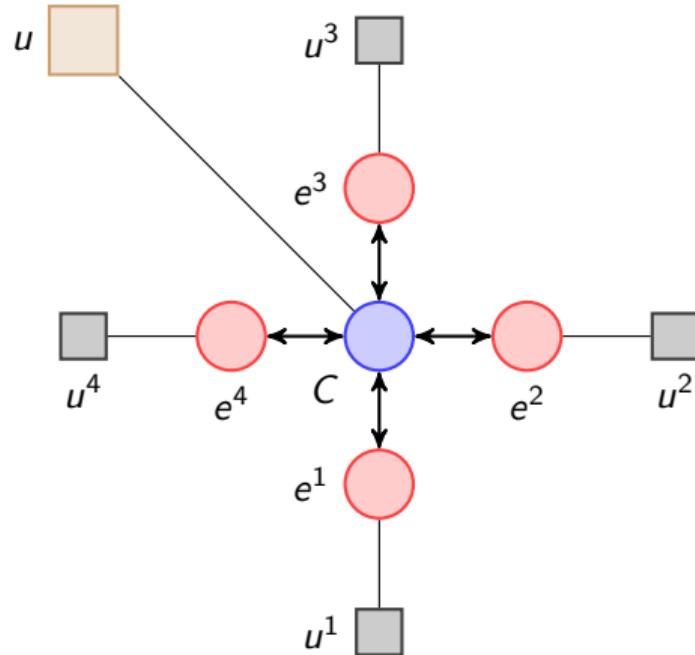


⁷ Michael P. Wellman, Eric Sodomka, and Amy Greenwald. "Self-confirming price-prediction strategies for simultaneous one-shot auctions". In: *Games and Economic Behavior* 201 (2017), pp. 339–372.

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.



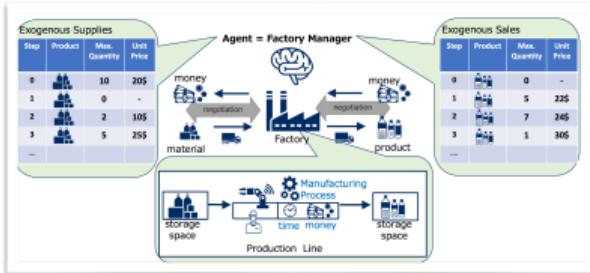
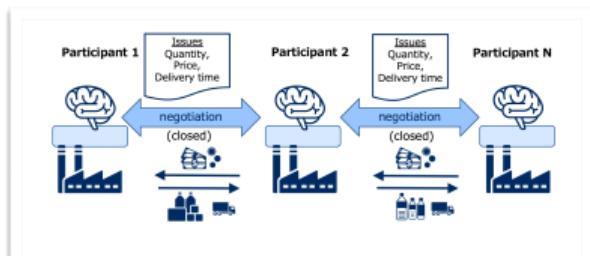
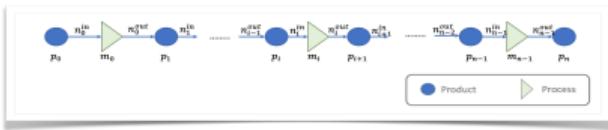
SCML World

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

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).
 - **Collusion track** → multiple factories (3).

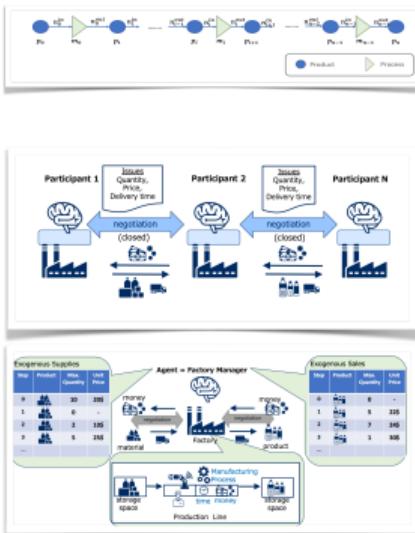
SCML Competition

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Flavors

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



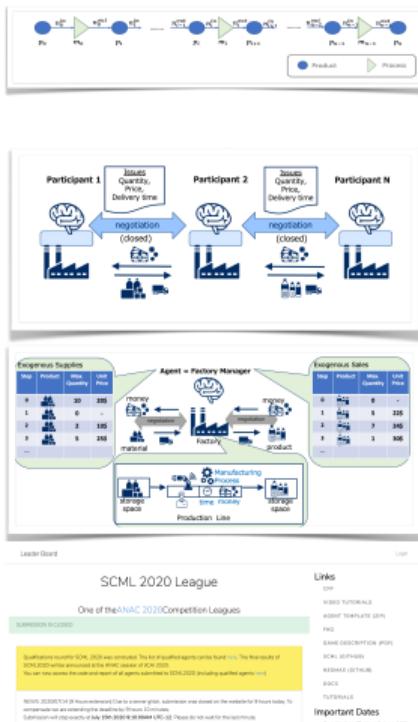
SCML Competition

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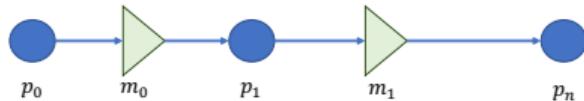
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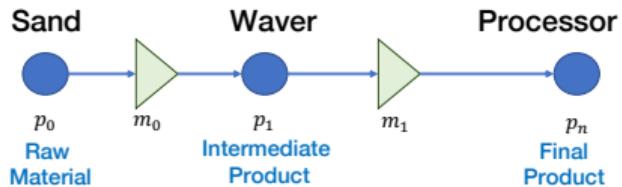
Overview



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



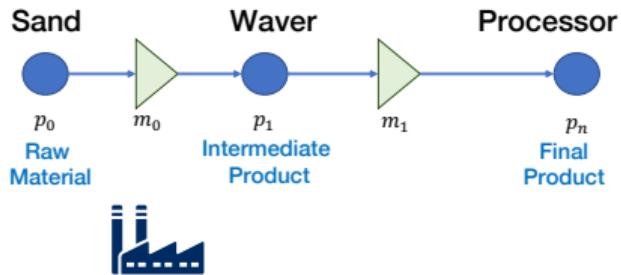
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- A **production-graph** defines what can be produced and how.
- We have 3 products, 2 processes.

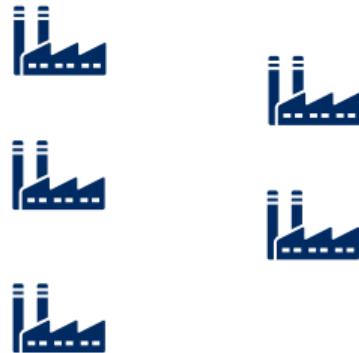
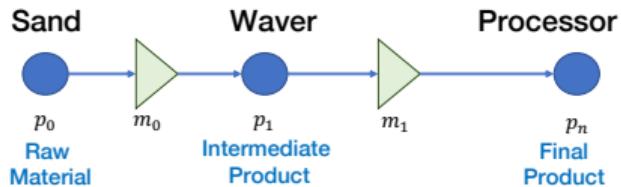


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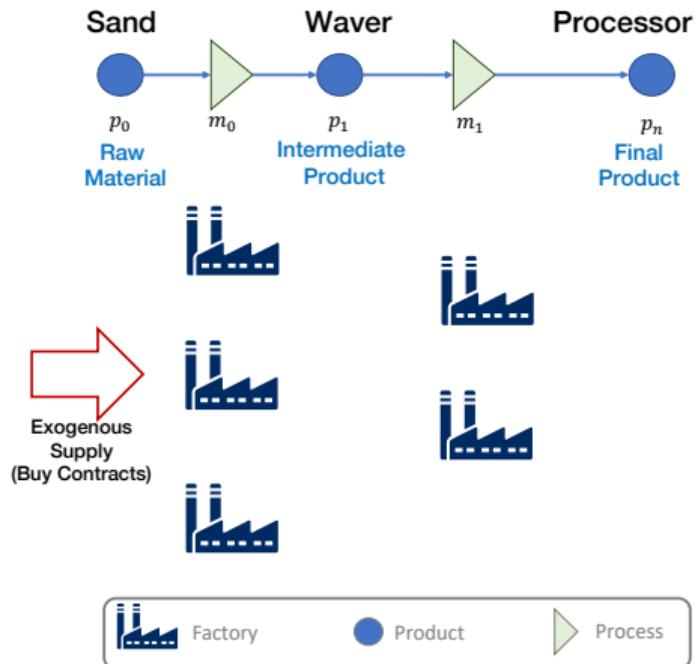
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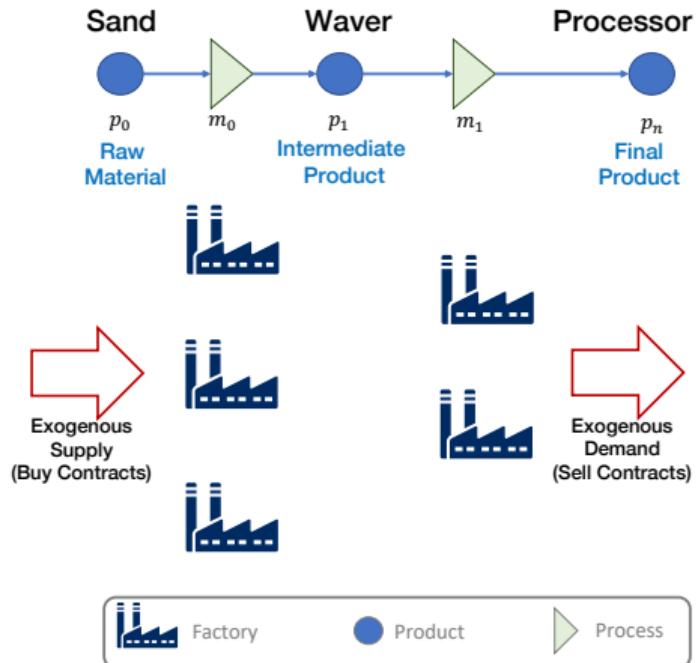
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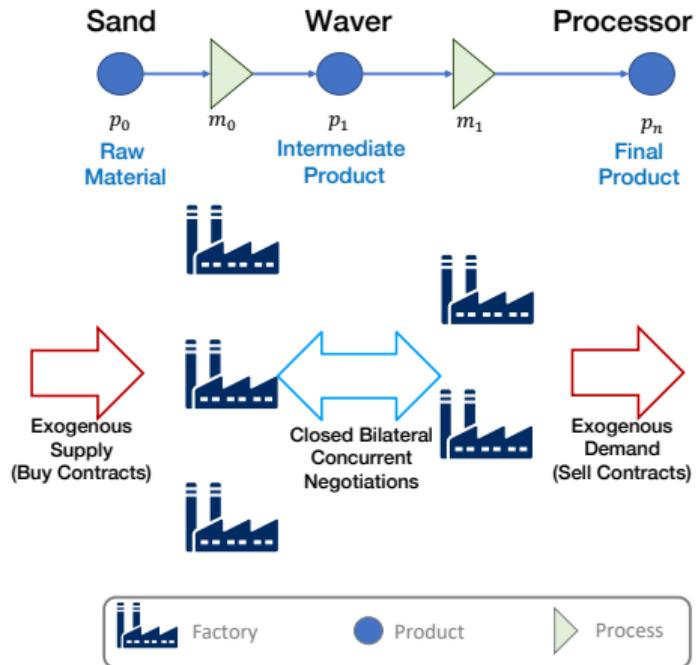
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Overview



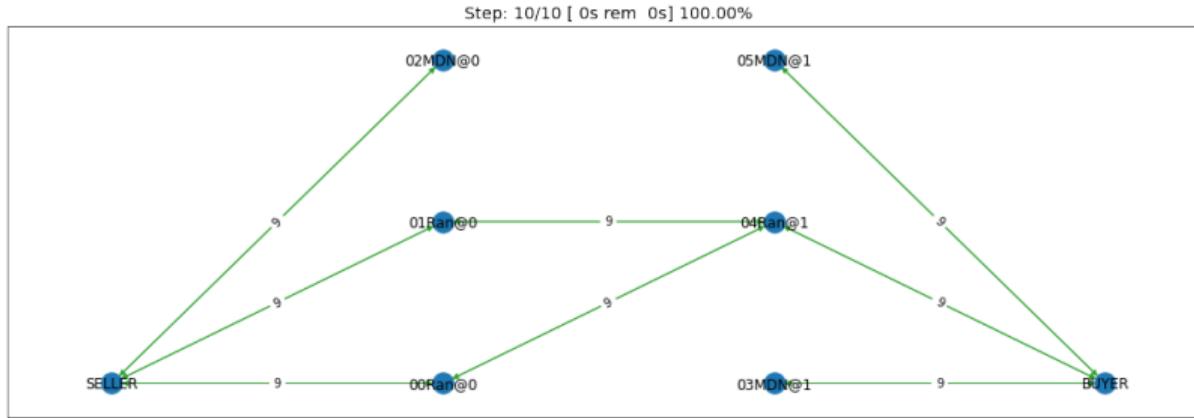
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- We have two layers of factories/agents.
- L_0 factories/agents receive exogenous supplies of **raw material**.
- L_1 factories/agents receive exogenous sales of **final product**.
- L_0 negotiate with L_1 agents to exchange **intermediate product**

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 accumulation).

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

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).

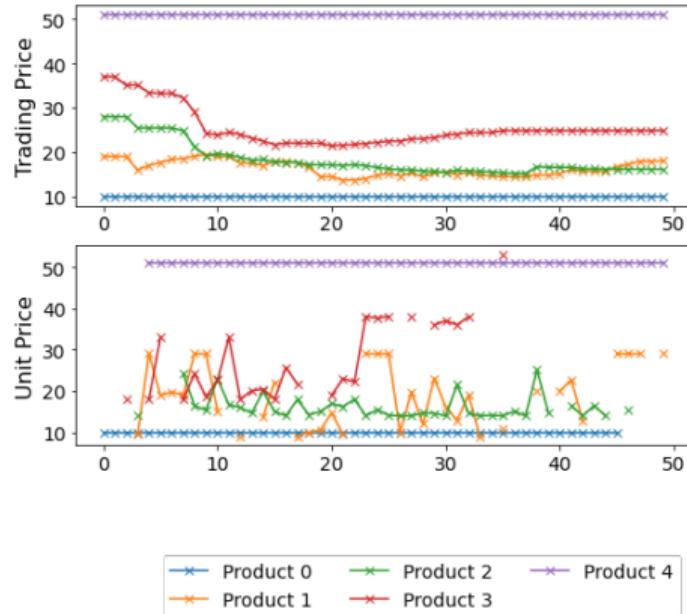
Market Information

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.



Product 0 Product 2 Product 4
Product 1 Product 3

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

Once



Simulation Steps

Once



Simulation Steps

Once



Simulation Steps

Once



Simulation Steps

Once



Simulation Steps

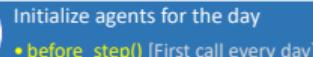
Once



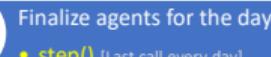
Every Day



Create exogenous contracts and sample agent's disposal cost, and shortfall penalty

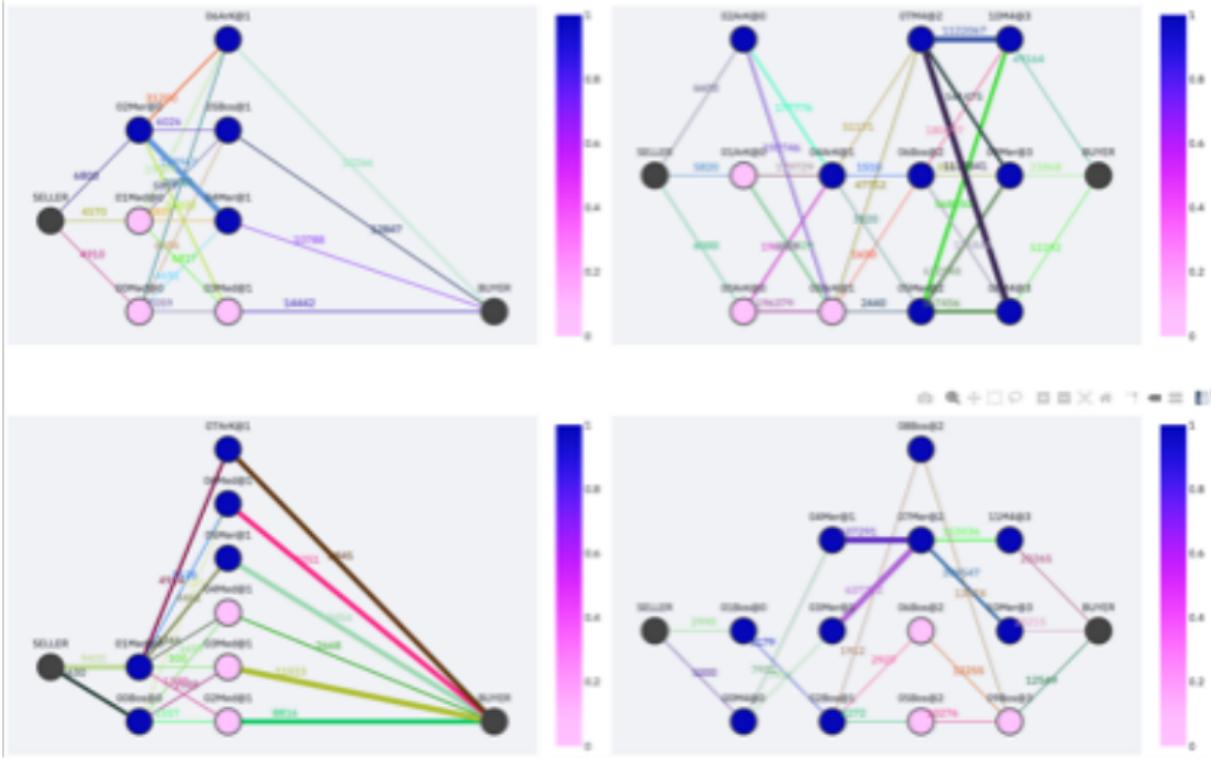


Calculate profits for all agents by simulating contract execution.



Publish Financial Reports

SCML Environment



Outline

1 Theoretical Session

- The Negotiation Problem
- Automated Negotiating Agents Competition: ANAC
- Supply Chain Management League: SCML
- **Anatomy of an Agent**

2 Development Environment

3 Development Example

SCML OneShot Agent

SCML Standard Agent

Outline

1 Theoretical Session

2 Development Environment

- Installing SCML
- Running a simulation
- Running a tournament
- Visualization and logging
- Troubleshooting and breathing time

3 Development Example

Outline

1 Theoretical Session

2 Development Environment

- **Installing SCML**
- Running a simulation
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3 Development Example

Installing SCML

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

1 Theoretical Session

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3 Development Example

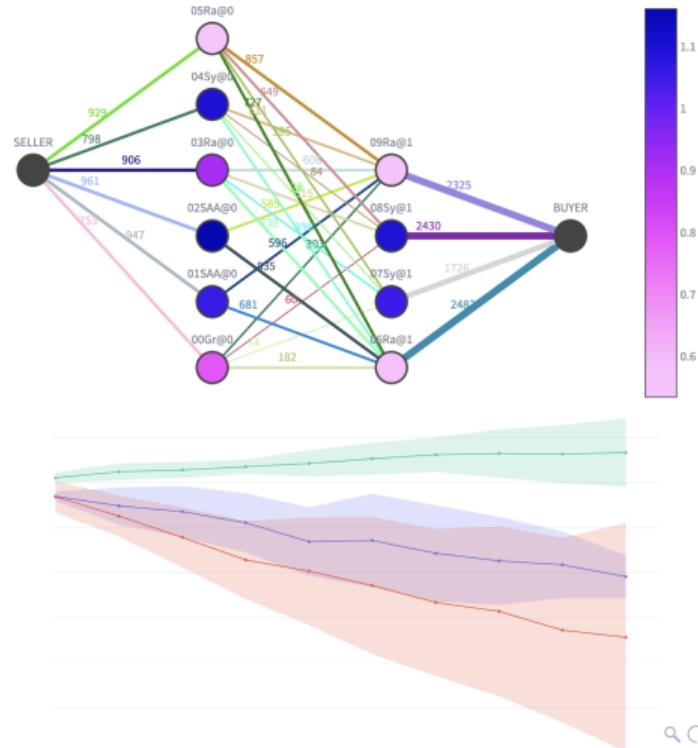
Running a single simulation (oneshot)

Command Line Tool

```
> scml run2024 —oneshot
```

Python

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



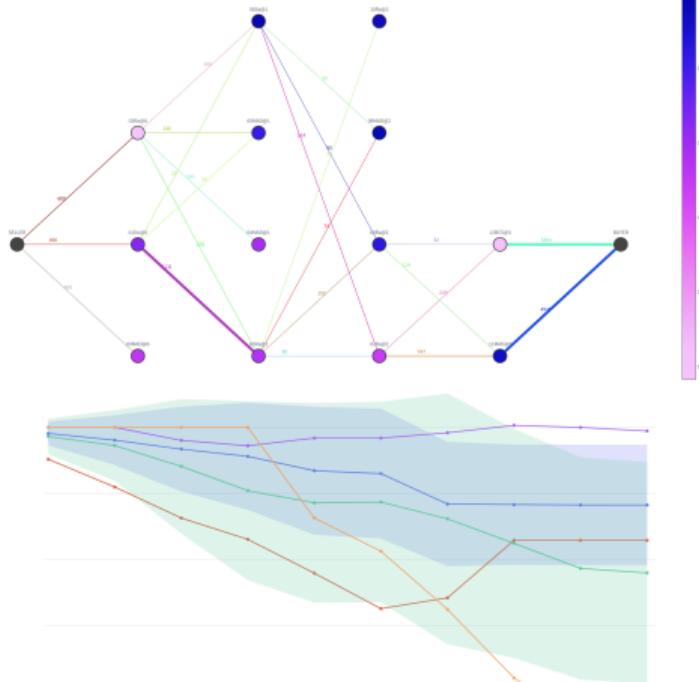
Running a single simulation (std)

Command Line Tool

```
> scml run2024
```

Python

```
SCML2024StdWorld(  
    **SCML2024StdWorld.generate(  
        agent_types=DefaultAgents2024  
    )).run()
```



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3 Development Example

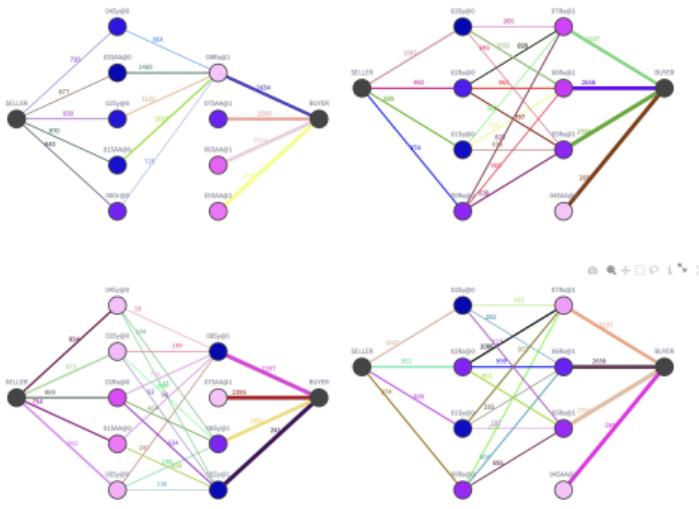
Running a complete tournament (oneshot)

Command Line Tool

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

Python

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



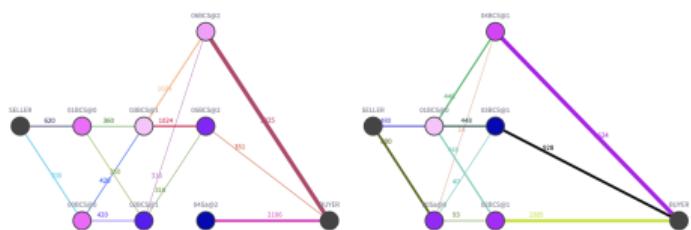
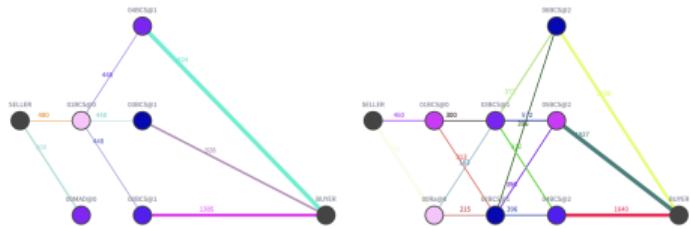
Running a complete tournament (std)

Command Line Tool

```
> scml tournament2024 --type=std
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Python

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anac2024_std(
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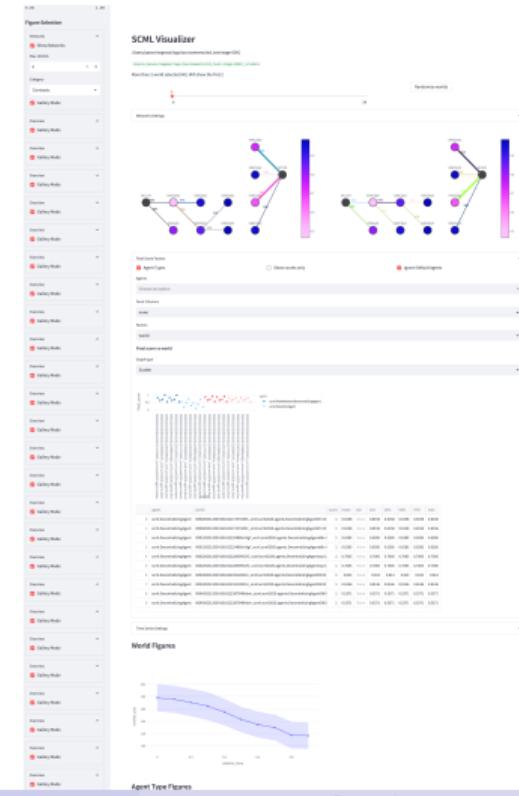


Visualization CLI

Command Line Tool

```
> scmlv show
```

		Inventory	Score	Market
20231129H194614733893Ps7-stage-	2.2 K	8000S0_0.n_A-RCFR.0008a55a		smrl.MarketAwareness
20231129H194641342854Lc-stage-	2.2 K	0001S0_1.H_A-R40d.016ed8bf		smrl.Usability
20231129H194846359611Uby-stage-08	1 K	0002S0_2.B_A-RUup.0242aa54		smrl.Randomization
20231129H194955076256MB4-stage-	2.2 K	0003S0_3.5_A-RWbm.03165be0		smrl.Satisficing
20231129H195118577752fJ-stage-	2.7 K	0004S1_0.q_A-RNHH.0499dc63		smrl.Decentralization
20231129H195216244186qsc-stage-	2.7 K	0005S1_1.p_A-R3ND.05a5a8bb		
20231129H19485262934603k-stage-08	1 K	0006S1_2.A_A-RnkF.068292d7		
20231130H080023219868Phm-stage-	960 B	0007S1_3.L_A-RSG8.077b18fc		
20231130H075912052957q6-stage-1.9	K	agent_stats.csv		
20231130H075932117366XNX-stage-1.1	K	agg_stats.csv		
DS_Store	14 K	assigned_configs.json		
Contracts		assigned_configs.pickle		
Gallery Mode		attempts		
Review		base_configs.json		
Show Overview		configs		
Score Distribution		kstats.csv		
Final Score Factors		params.json		
Rules		partner_advantage.csv		
		partner_utility.csv		
		received_advantage.csv		
		received_utility.csv		
		score_stats.csv		
		scores.csv		
		stats.csv		
		total_advantage.csv		
		total_scores.csv		
		tstats.csv		
		type_stats.csv		



Outline

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3 Development Example

Troubleshooting and breathing time



Outline

- ① Theoretical Session
- ② Development Environment
- ③ Development Example
 - Anatomy of An Agent
 - SCML Builtin Strategies
 - Example Agent Strategies

Outline

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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

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Greedy Random Agent



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Example Winner Agents



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