Introducing Bounded Rationality into Self-Organization-Based Semiconductor Manufacturing

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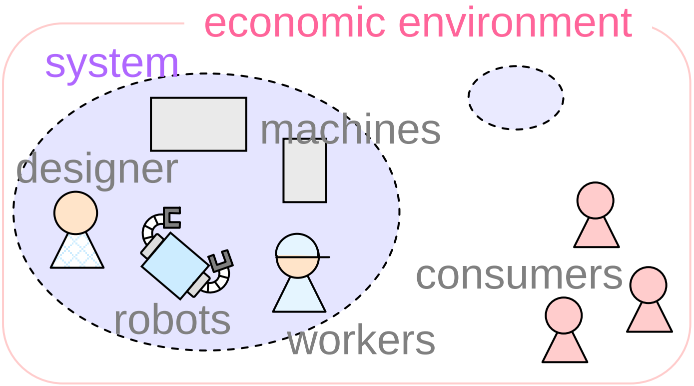
INTRODUCTION (1)

Manufacturing systems

- consist of various agents
- are placed in complex and dynamic environment
- achieve the goal: efficient production



Optimality < Adaptivity, Flexibility

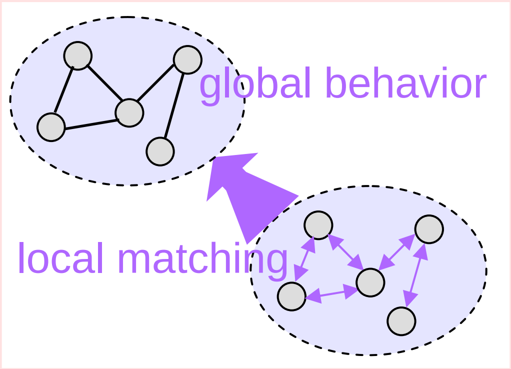
~~Top-down approach~~

Bottom-up approach
Agent-based approach

Biological Manufacturing Systems (BMS) [Ueda 1987]

BMS is a next-generation manufacturing system model, which adapts to unpredictable changes in complex environments, based on biologically-inspired ideas.

Self-organization-based BMS

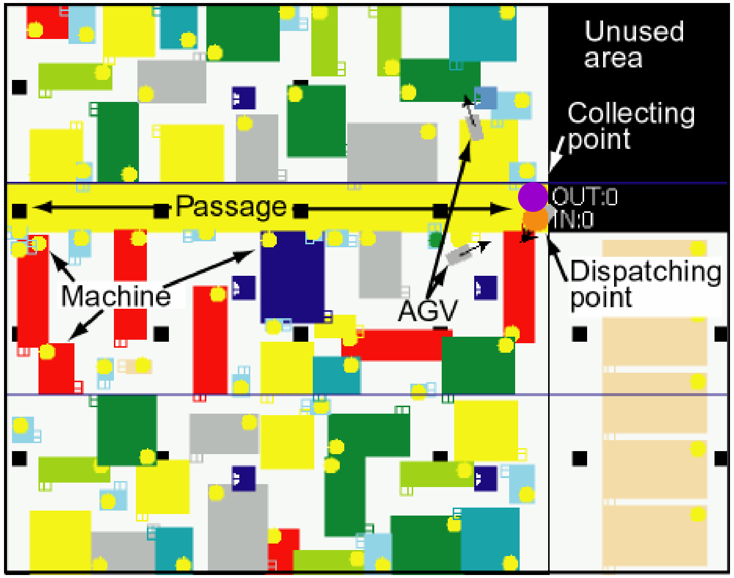


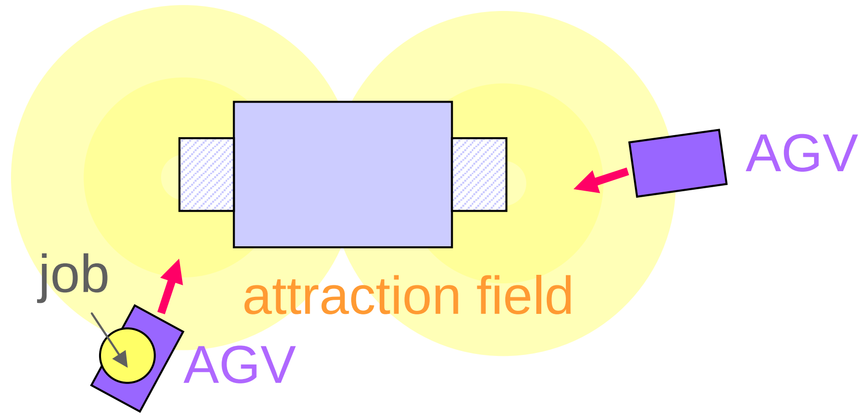
Production process emerges, as the global behavior, from local interactions among the system elements.

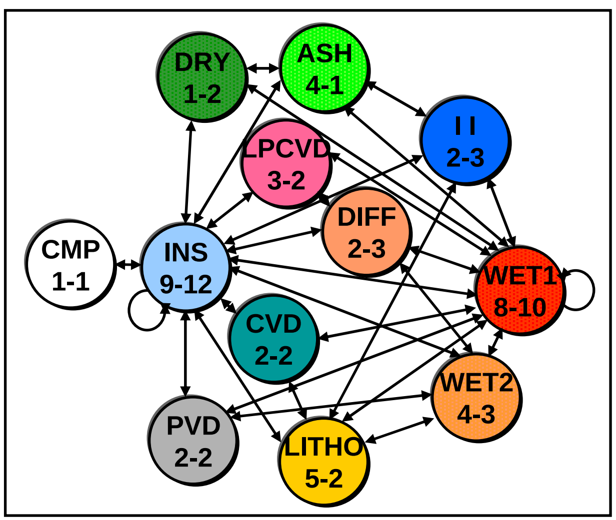
Local interaction: matching between the capabilities of the machines and the requirements of the jobs.

INTRODUCTION (2)

Self-Organization-Based Semiconductor Manufacturing Systems







The machine generates an attraction force according to its capability.

An AGV senses the accumulated potential fields of machines with capabilities that match the product it is transporting (or “not transporting”).

INTRODUCTION (3)

Local competitions

- Multiple AGVs gather at one machine to receive a product simultaneously
- an AGV senses fields generated by multiple machines simultaneously

Such situations occur because…

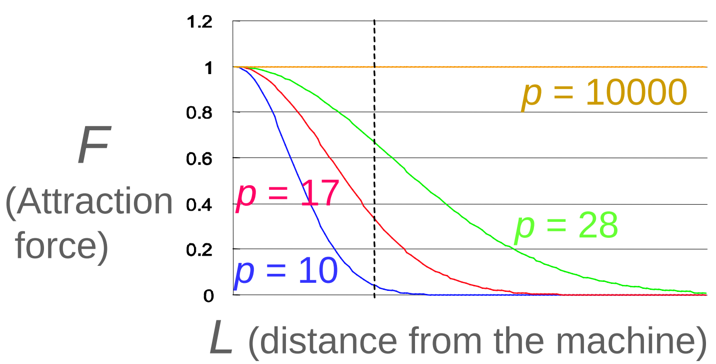
potential fields pervade the floor; spatial restriction is not considered.

(1) Limiting information generation

Machines limit the area in which their generated potential fields spread.

"Information Localization" [Kuraoka 06]

$F_i(L) = \exp(-L^2 / p_i^2)$



(2) Limiting information usage

AGVs limit the area in which they sense potential fields.

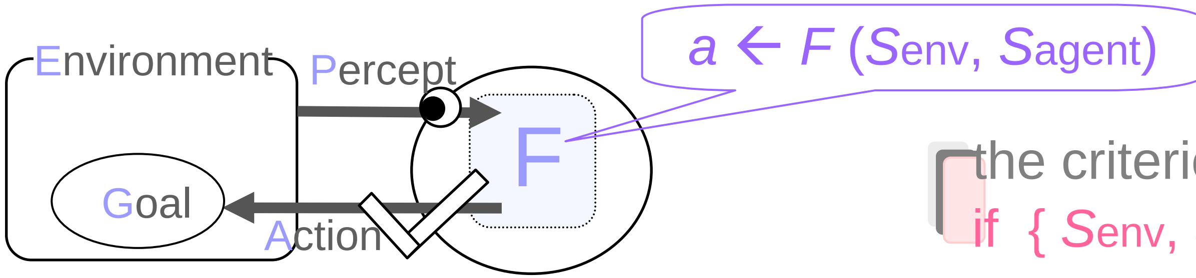
"Introduction of **Bounded Rationality**"

A human specific characteristic of decision-making; being partly rational

The objective of this presentation is…

to show the effectiveness of introducing bounded rationality through comparison to information localization.

INTRODUCING BOUNDED RATIONALITY



- the criterion:
  if { Senv, Sagent } = { Senv, Sagent }

The design approach for bounded-rational agents is introducing

“incompleteness” into incentives for being rational (not pursuing optimality)

- When the input of the decision-making function matches the criterion, choose the alternative that is derived as the rational behavior using not all the input information but a fraction of it.

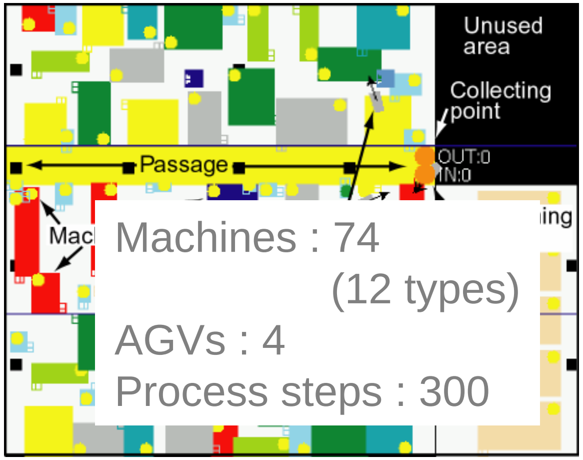
(Type-0) The AGV consistently limits the distance range of the sensing area.

Limitation incentives

(Type-1) The AGV limits the sensing area if the number of times it carries products is greater than the average number of times the other AGVs carry them.

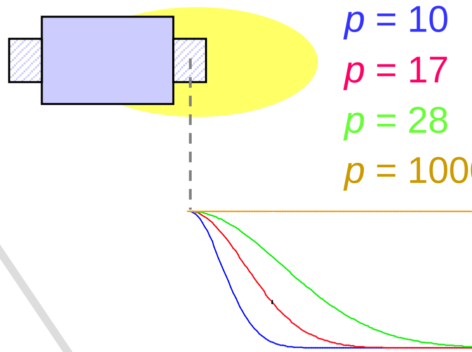
(Type-2) The AGV limits the sensing area if the distance it moved is greater than the average distance the other AGVs moved.

SIMULATION SETTING



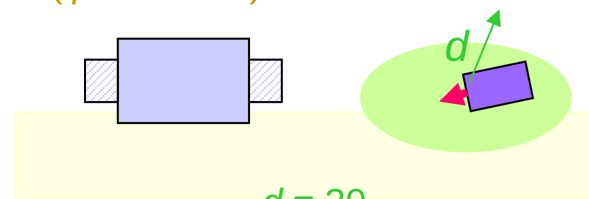
Experiment-1

information localization



introducing (Type-0) AGVs

(*p* = 10000)

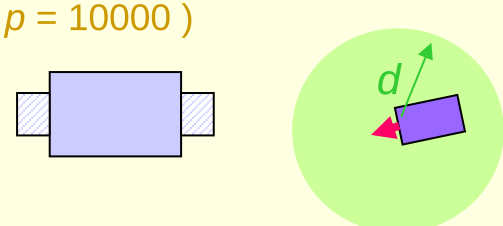


d = 30
d = 40
d = 50
d = 60

Experiment-2

- introducing (Type-1) AGVs
- introducing (Type-2) AGVs

(*p* = 10000)



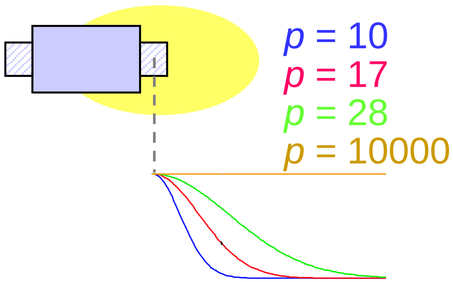
d = 60 → *d* = 40

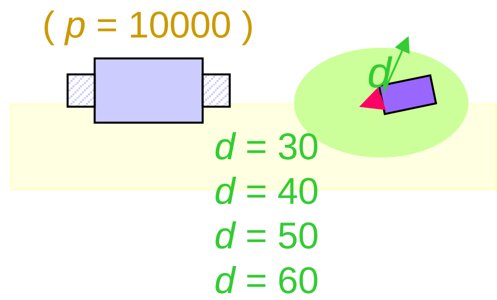
if the input of the decision-making function matches the criterion.

Experiment-3

<u>under changing environments:</u>
machines break down with a certain probability

EXPERIMENT-1





WIP (work in process)
TAT (turn around time)

information localization

	p = 10	p = 17	p = 28	p =10000
WIP(Lot)	71[illegible]46	68.84	70.[illegible]6	73[illegible]7
TAT(day)	6.[illegible]4	6[illegible]19	6.4[illegible]	6.65
Mileage(m)	4786.9	46[illegible]6.8	4730.1	4802.4

global information

p = 17
d = 40

introducing (Type-0) AGVs

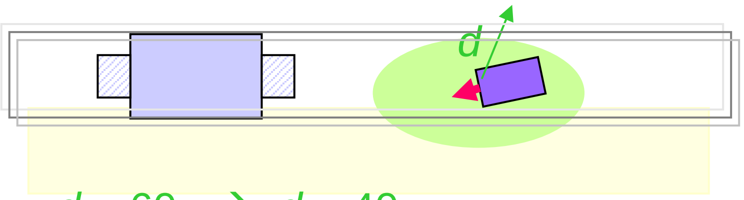
	d = 30	d = 40	d = 50	d = 60
WIP(Lot)	71[illegible]11	68.10	72.00	72[illegible]8
TAT(day)	6.[illegible]0	6[illegible]17	6.5[illegible]	6.60
Mileage(m)	4724.8	46[illegible]4.3	4698.0	4784.3

Both ways of considering spatial restriction are effective for improving the system performance.

EXPERIMENT-2

- introducing (Type-1) AGVs
- introducing (Type-2) AGVs

(*p* = 10000)



d = 60 → *d* = 40

if the input of the decision-making function matches the criterion.

(Type-1)

The AGV limits the sensing area if the number of times it carries products is greater than the average number of times the other AGVs carry them.

(Type-2)

The AGV limits the sensing area if the distance it moved is greater than the average distance the other AGVs moved.

	p = 17	*d* = 40	Type-1	Type-2
WIP(Lot)	68.84	68.10	67.66	67.81
TAT(day)	6.19	6.17	6.00	6.11
Mileage(m)	4696.8	4684.3	4498.5	4492.3

Although all the AGVs have identical simple decision-making functions, they sometimes sense a distant field and sometimes not.

Various behaviors offer the potentiality to accelerate a kind of role-sharing, and thereby improve the system performance.

EXPERIMENT-3

<u>under changing environments:</u>
machines break down with a certain probability

	p = 10000	*p* = 17	Type-1	Type-2
WIP(Lot)	98.41	78.75	77.53	77.44
TAT(day)	8.87	7.11	7.00	6.96
Mileage(m)	4927.2	4789.2	4600.1	4587.4

- Compared to the case of *p* =10000, the case of *p* =17 maintains the performance.

  ➡ Limiting information would be effective under changing situations.

- In the case of Introducing (Type-1) or (Type-2) bounded-rational agents, the system performance can be retained at a higher level than in the case of *p* =17.

  ➡ Because bounded-rational agents choose their actions according to situations of the environment and their internal states, they can be more flexible or adaptive to changing environments than when considering information localization.

CONCLUSION

- This study proposes a design approach for self-organization-based systems by introducing bounded-rational agents, which is effective to solve the problem of local competition that occurs among agents.

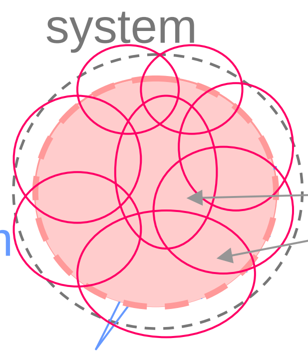
- Bounded rationality was modeled from the standpoint of not using all information that the agent can perceive when the input of the decision-making function matches the criterion.

- Simulation results show that :
  - both models of “information localization” and “introduction of bounded rationality” can be effective to improve the system performance.
  - bounded rationality might be the key to endowing the system with added frexibility and adaptivity to solve local competition under changing situations.

To deal with multi-agent systems in the real world, with environments and structures which are complex and uncertain,
introducing bounded-rational agents can be an effective approach to derive adaptive solutions.

INTRODUCTION (2)

Artifactual system



- designs the goal from outside the system

- assigns parts of the goal to multiple agents as local goals, by taking into account limitation of ability

(Distributed problem solving)

$$G \neq \bigcup_{k=1}^{n} L_k$$

(G: global goal, L_k: local goal (k=1, …,n))

Local competition between agents

Dilemmatic situations between the global goal and agents' local goals

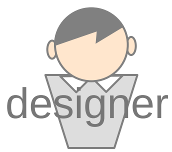
Existing effective methods:

- introducing a superior agent who can command other agents
- forcing goals to be shared among agents
- distributing rewards of attaining the system goal among all agents

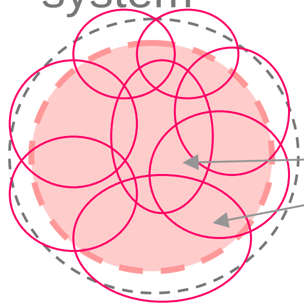
…It is difficult to
- introduce a superior agents
- perceive information of the whole system or other agents

INTRODUCTION (2)

Artifactual system



system



$$G \neq \bigcup_{k=1}^{n} L_k$$

(G: global goal, L_k: local goal (k=1, …,n))

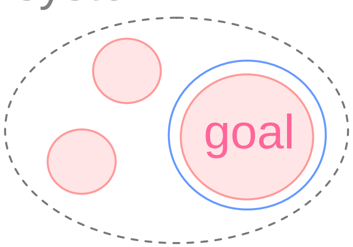
Local competition between agents

Dilemmatic situations between the global goal and agents' local goals

Social system

➡ flexible, adaptive, robust

system



- avoidance of competition
- resolution of the dilemma
- **role-sharing**
- **altruism**

Bounded Rationality [Simon]

A human specific characteristic of decision-making; being partly rational

Agents' bounded rationality has positive aspects to its use in artifactual systems!

Explicit consideration of bounded rationality is essential to depart from the traditional paradigm!

OBJECTIVE

This study discusses the potentiality of introducing bounded rationality into constituent agents of a multi-agent system.

Introduction of Bounded Rationality

- Concept of bounded rationality
- Modeling bounded rationality

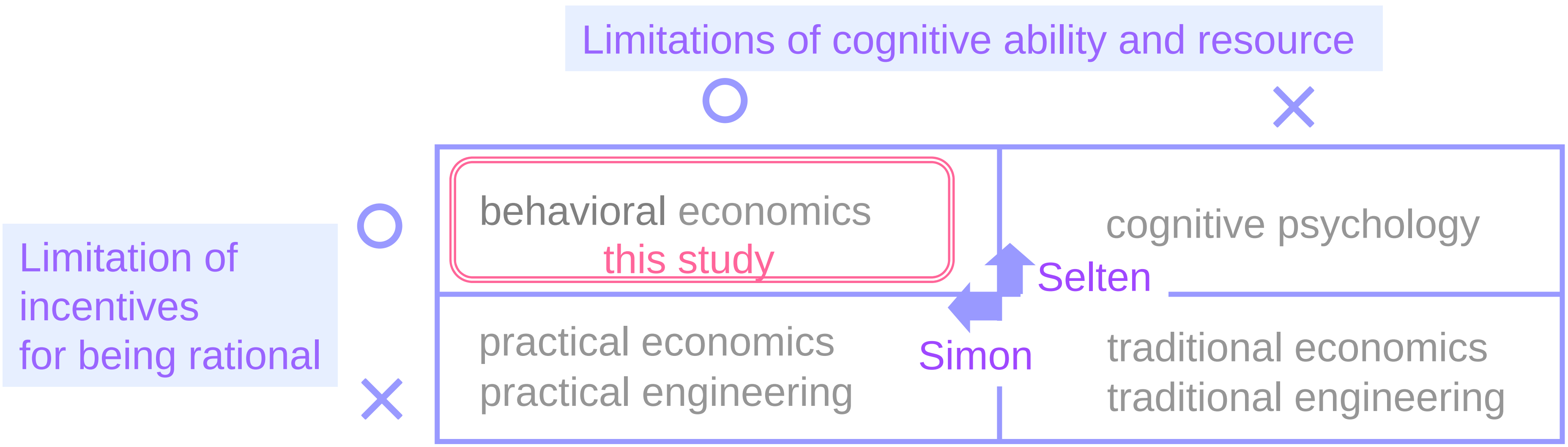
Verification Experiments: Self-Organization-Based Biological Manufacturing Systems

- Model of self-organization-based BMS
- Bounded-rational agent models in s-o BMS
- Simulation results

Discussion and Conclusion

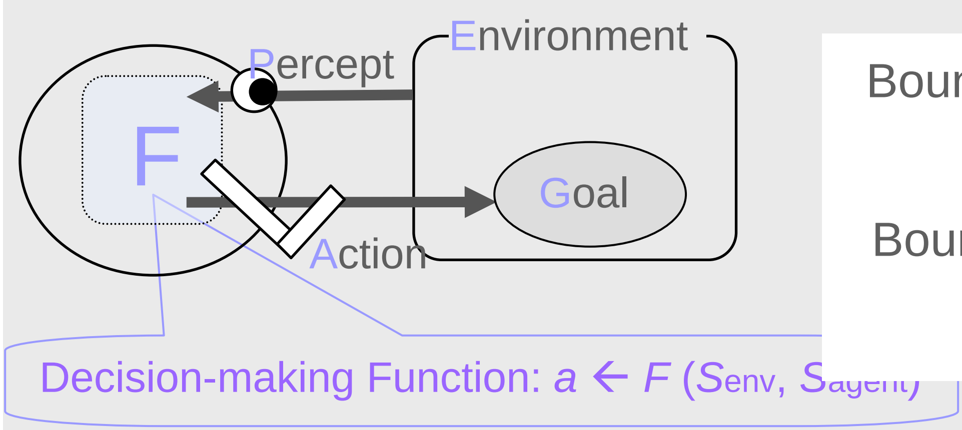
- Association between types of “incompleteness” and “bounded rationality”

Concept of Bounded Rationality



The design approach for bounded-rational agents is…

introducing "incompleteness" into incentives for being rational (not pursuing optimality)



Bounded rationality as constraints

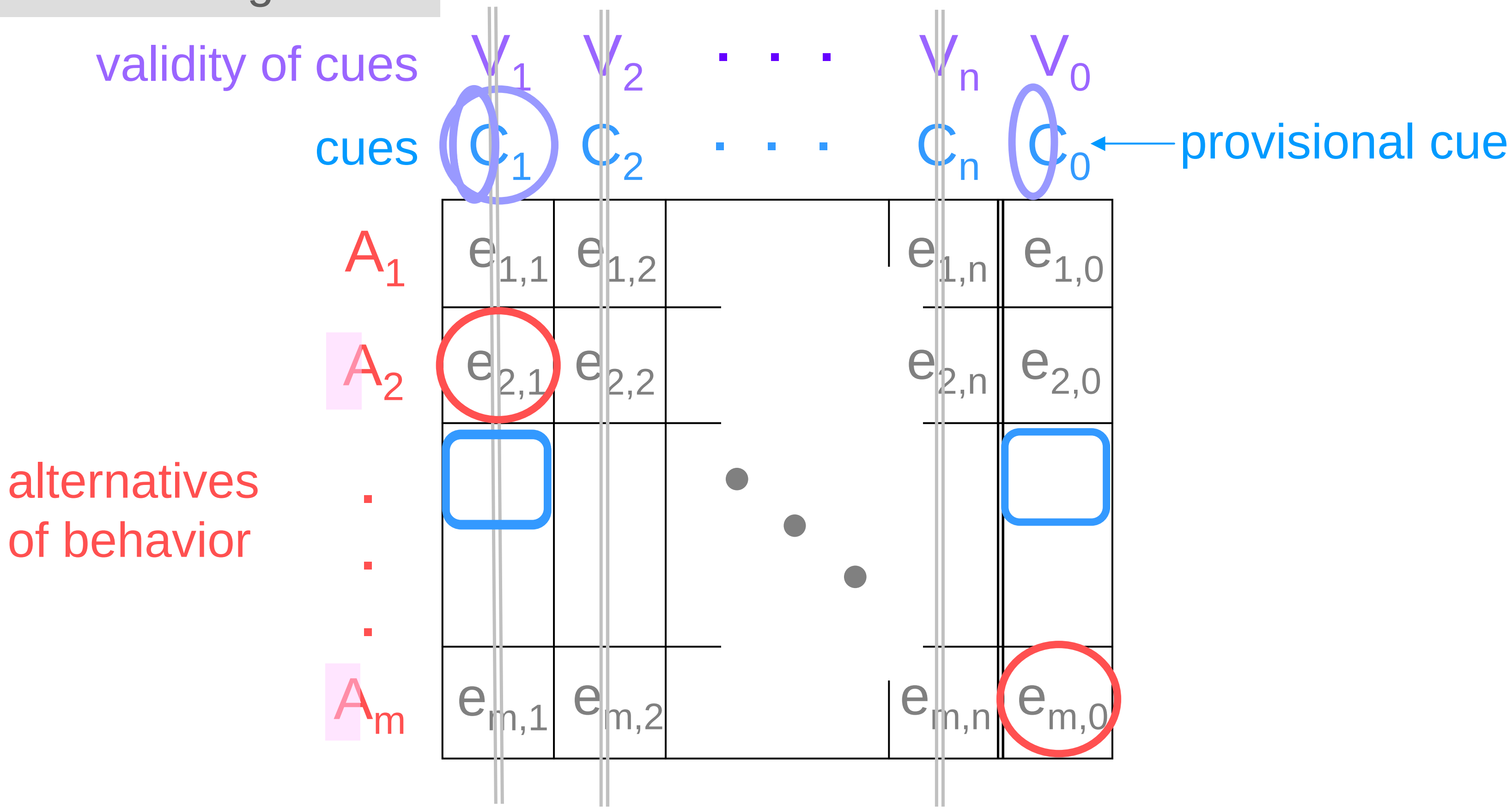
➡ **incompleteness of "PAGE"**

Bounded rationality designed by our approach

➡ **incompleteness of "F"**

Modeling Rationality

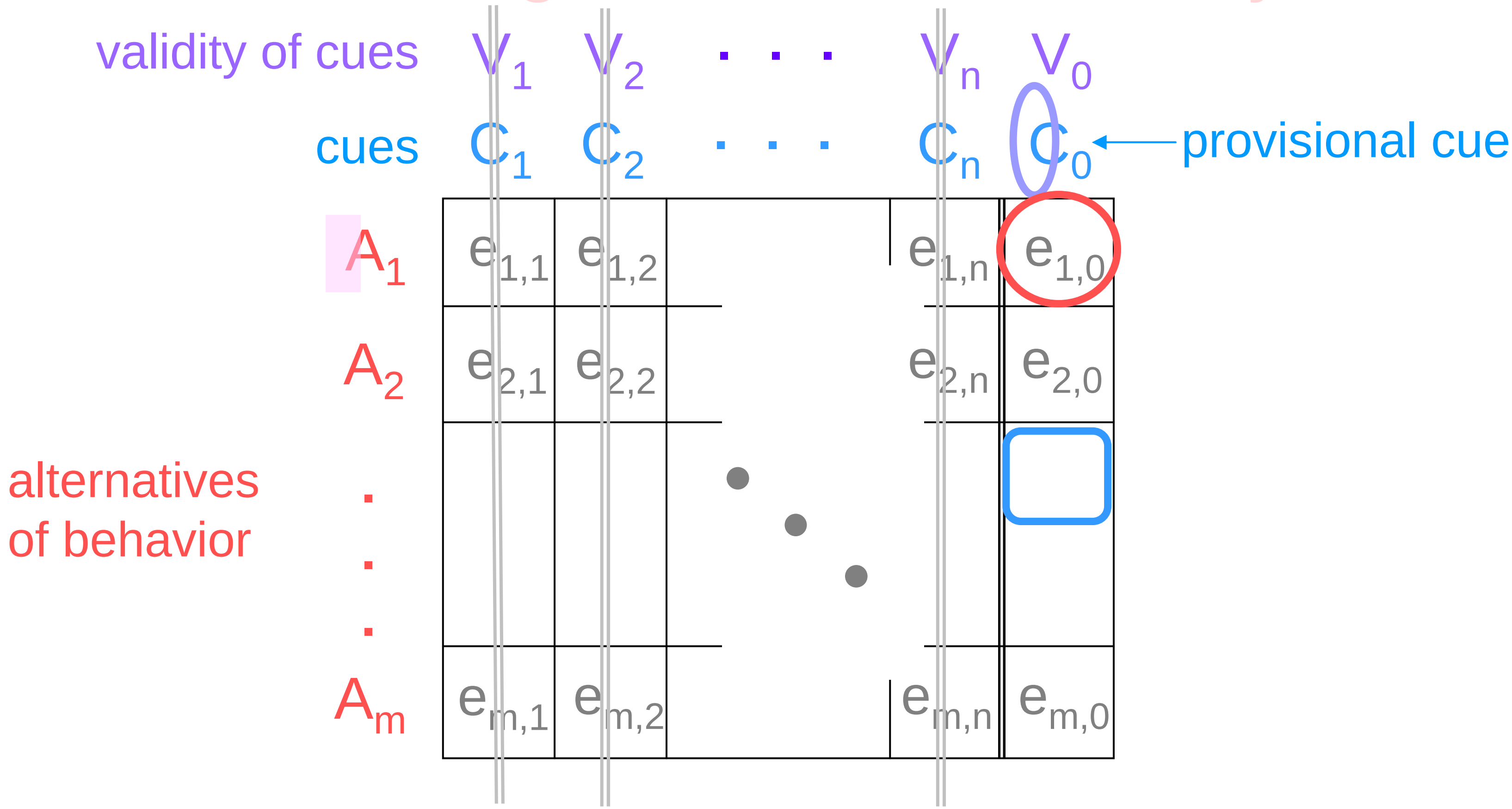
Decision-Making Matrix



DECISION-MAKING PROCEDURES

(1) List up the practicable alternatives of behavior
(2) According to the information that is the clue for choosing (=“cue”), compare the utility of the alternatives
(3) Choose one alternative as the behavioral solution, of which the utility is the highest

Modeling Bounded Rationality



bounded-rational decision-making: **incompleteness of usage of V**

$S_{env} = S'_{env}$ || $S_{agent} = S'_{agent}$

⇒ $V = 0$

Three types
- S'_{env}
- S'_{agent}
- $S'_{env} + S'_{agent}$

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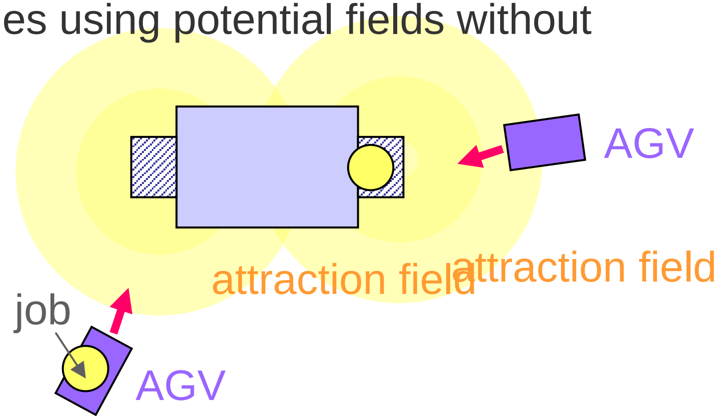
Self-Organization Based BMS

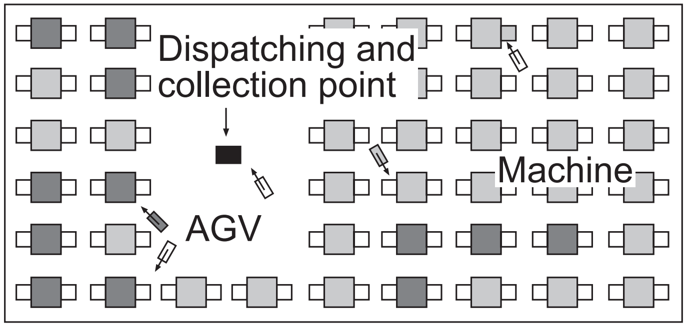
Outline of Biological Manufacturing Systems (BMS) [Ueda 1988]

A manufacturing system concept to deal with complexity and uncertainty based on emergent synthesis methodologies including biologically-inspired ideas.

Self-organization-based BMS

The model of BMS in which the production proceeds as a result of matching of job requirements and machine capabilities using potential fields without global control.





floor layout

machines: 44
AGVs: 4
jobs: 217

Local competition between AGVs:

- <u>Temporal competition:</u>
  multiple AGVs gather at one machine to get a job at the same time
- <u>Spatial competition:</u>
  multiple AGVs must pass through a narrow aile

Bounded-Rational Agent Model

	V_1 1	V_0 0
	C_1 attraction field	C_0
Move to field source(s)	{1， 0}	0
No action	{1， 0}	1

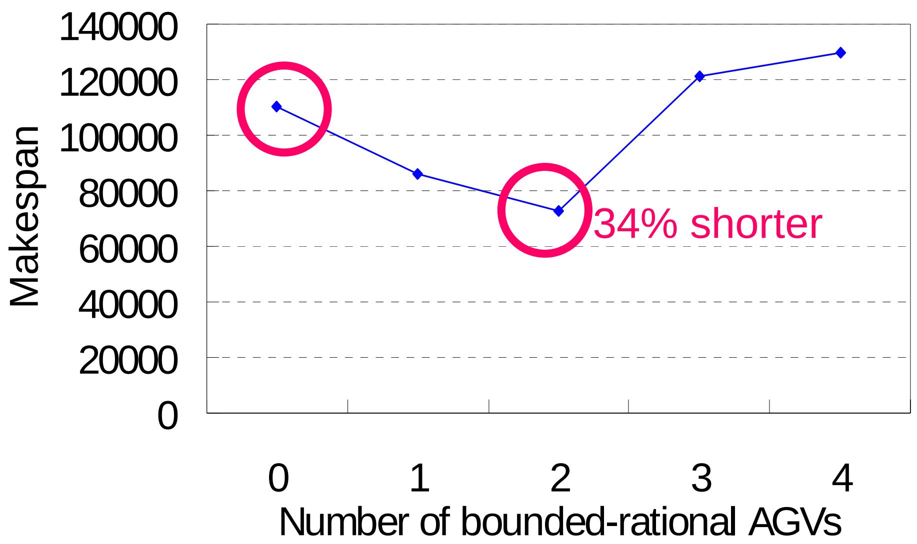
(Type-1) the criterion for the agent's internal state ($S_{agent} = S'_{agent}$)

For a short while after the AGV picks up or places a job, it performs no action, even though it feels attraction fields.

(Type-2) the criterion for the perceptual information and the agent's internal state ($\{S_{agent}, S_{env}\} = \{S'_{agent}, S'_{env}\}$)

If the number of times the AGV carries jobs is greater than the average number of times the other AGVs carry them, it performs no action even though it senses attraction fields.

Simulation Results: (Type-1)



Number of times each AGV carries jobs

AGV No.	1	2	3	4
R*4	101	102	120	111
R*2, BR*2	165	167	52	50

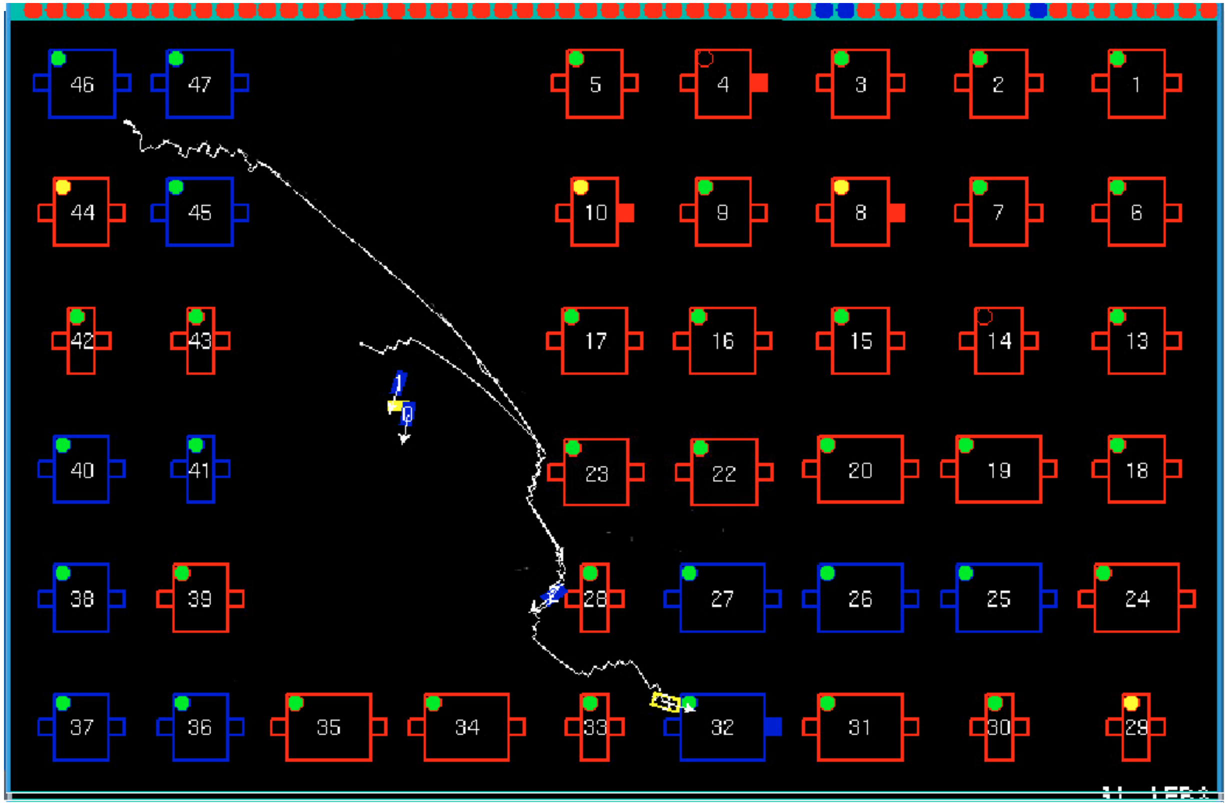
The makespan became 34% shorter when two AGVs were bounded-rational than when all AGVs were rational.

➡ (Type-1) AGVs contributed to improving the system performance.

Improvement of the system performance was achieved through the behavior by which bounded-rational AGVs moved to obtain other jobs whereas the rational AGVs grouped together to move to get the same job.

➡ Altruistic behavior and role sharing emerged.

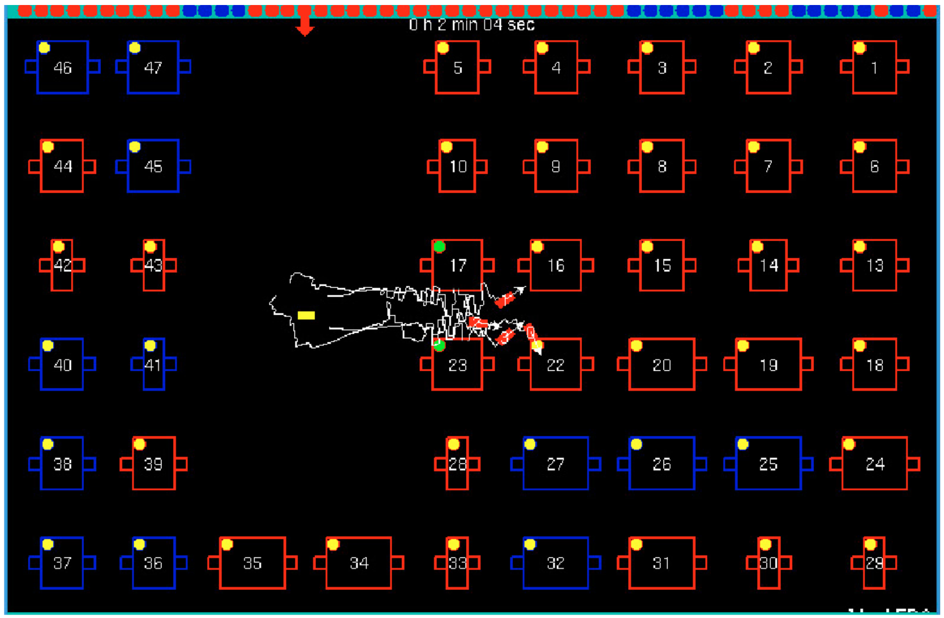
Avoidance of Temporal Competition



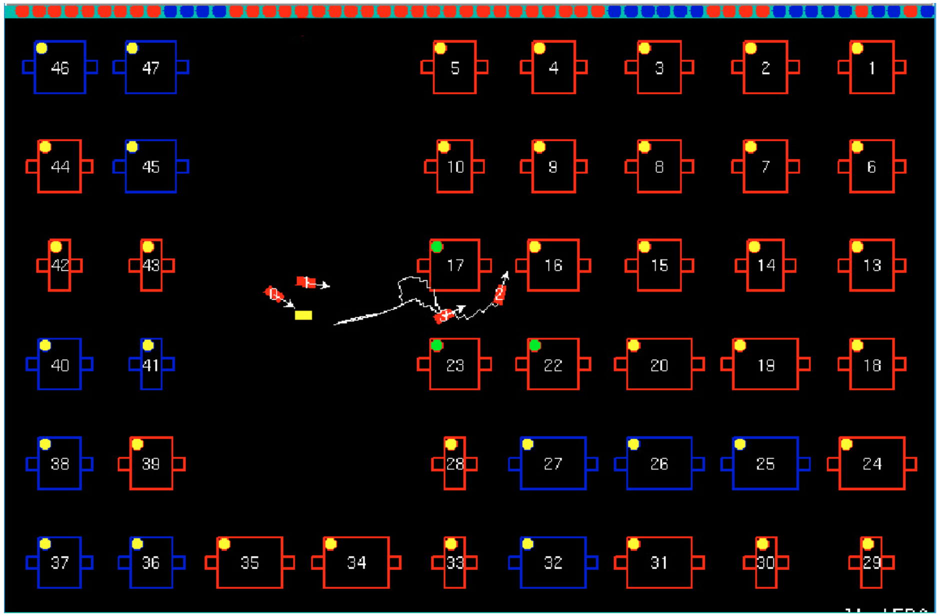
<u>Case 1:</u>
Four rational AGVs

<u>Case 2:</u>
Two rational AGVs and two bounded-rational AGVs

Avoidance of Spatial Competition



Case 1: Four rational AGVs



Case 2: Two rational AGVs and two bounded-rational AGVs

By introducing bounded rationality, temporal competition and spatial competition between agents were avoided

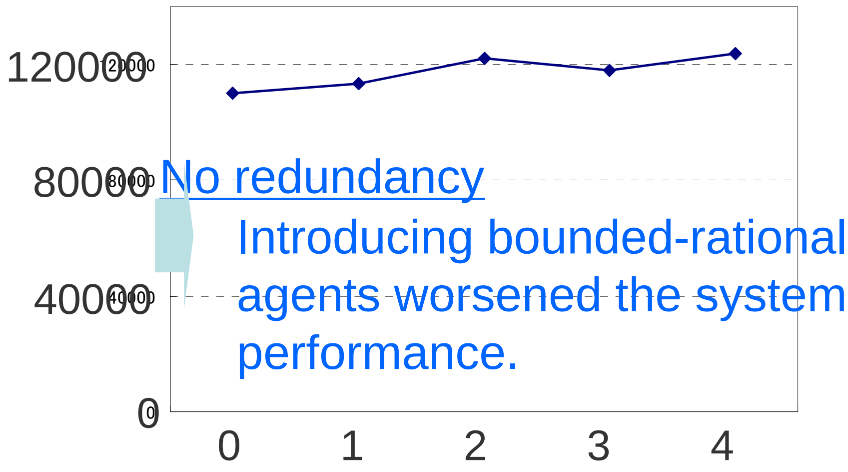
System performance was improved

Simulation Results: (Type-2)

(Type-2): the AGV neglects carrying jobs when it carries more jobs than the others.

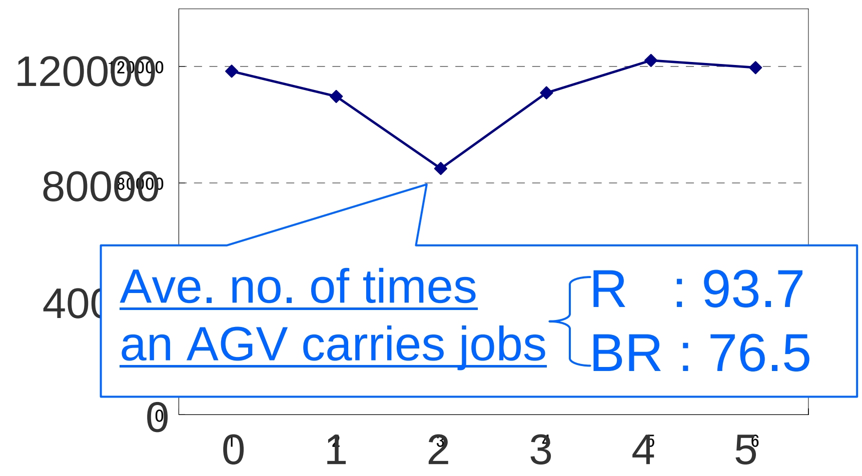
Makespan

Total number of AGVs: 4



No. of bounded rational AGV(s)

Total number of AGVs: 5



No. of bounded rational AGV(s)

- Bounded-rational AGVs contributed to improving the system performance.
- Amount of works of (Type-2) AGVs was not so less than rational AGVs, compared with the case when (Type-1) AGVs were introduced.

Local competition was adaptively-avoided, according to the situations or conditions of environment and the other AGVs.

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Discussion and Conclusion

Bounded rationality might be the key to endowing the system flexibility and adaptivity to solve temporal and spatial competition; it might also engender altruism.

Two types of bounded rationality

(Type-1) criterion for the agent's internal state

The agent decides whether it uses the cue or not, based on the **norm** that exists inside it.

→ effective if variations of the environmental changes or incompleteness are within the scope of the assumptions, even though the degree of them is unknown.

(Type-2) composite criterion for the perceptual information and agent's internal state

Bounded-rational behaviors develop when the norms are adapted to the environments.
(→ less sensitive to conditions of the environment)

→ effective if variations itself of the incompleteness are unknown or unpredictable. By changing the norm according to situations, it behaves adaptively.

Introducing appropriate bounded-rational agents can be an effective approach to derive adaptive solutions under incomplete conditions, while obviating the need for top-down control or provision of global information and rules.

AGVの意思決定モデル

	V_1	V_0
	1	0
	C_1 引力場	C_0
力の方向に動く	{1，0}	0
その場で回転	{1，0}	1

(Type-2)：S_{agent} の条件

製品を搬送し終えてから
t ステップ以内であるとき
($t = 80$)

しばらく休む

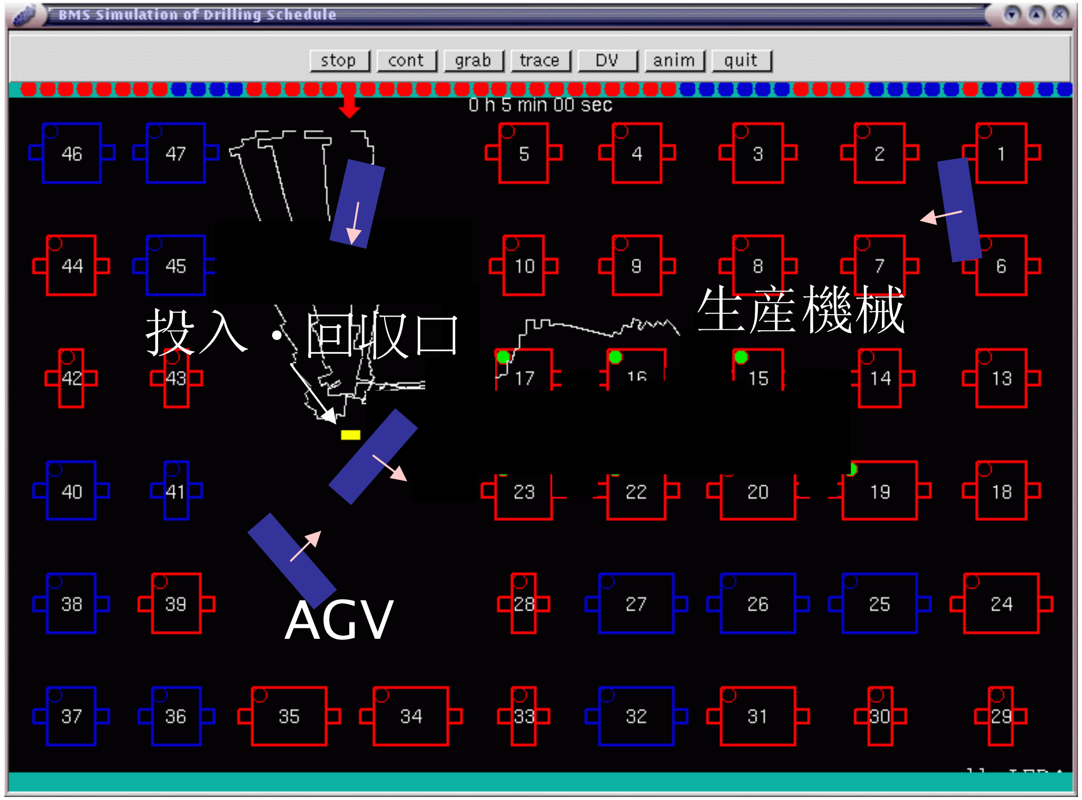
(Type-3)：S_{env} と S_{agent} の条件

自分の製品搬送回数が，他の
AGVの搬送回数の平均値を
上回るとき

働きすぎると怠ける

実験設定

多層プリント基板の穴あけ工程フロア



生産機械：44台

2種類の生産能力 {加工精度、ボードサイズ}

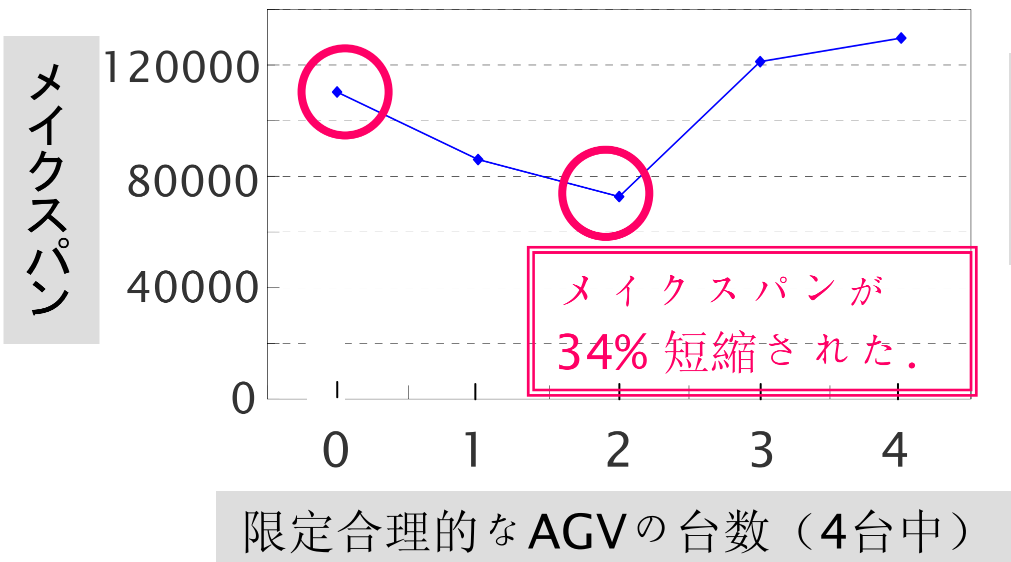
製品：217個

2種類の生産能力 {加工精度、ボードサイズ}

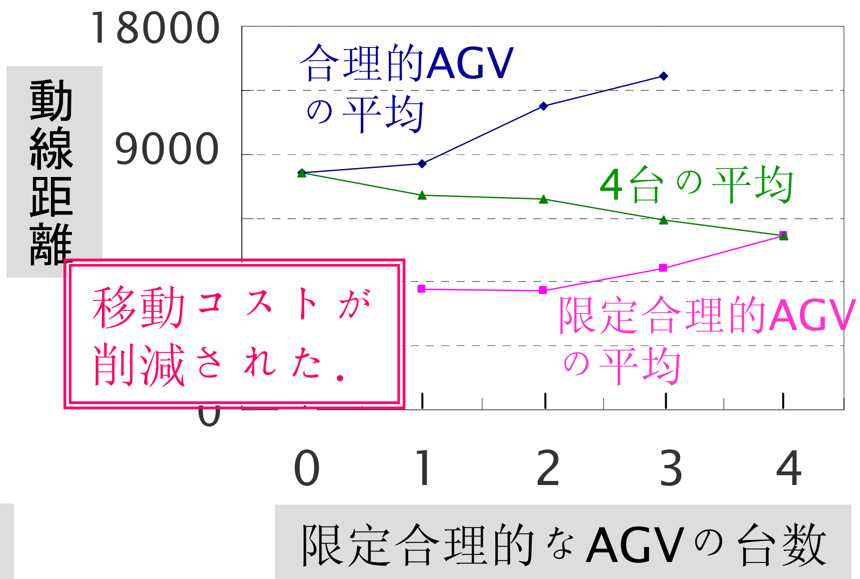
投入された全ての製品が，加工工程を終えて，回収口に回収されれば終了．(最初の投入～最後の回収の時間：メイクスパン)

十分な作業効率を保つことが出来るAGVの最少台数 ＝ 4台

実験結果：(Type-2)の導入



メイクスパンの変化



平均動線距離

表：各AGVの製品搬送回数

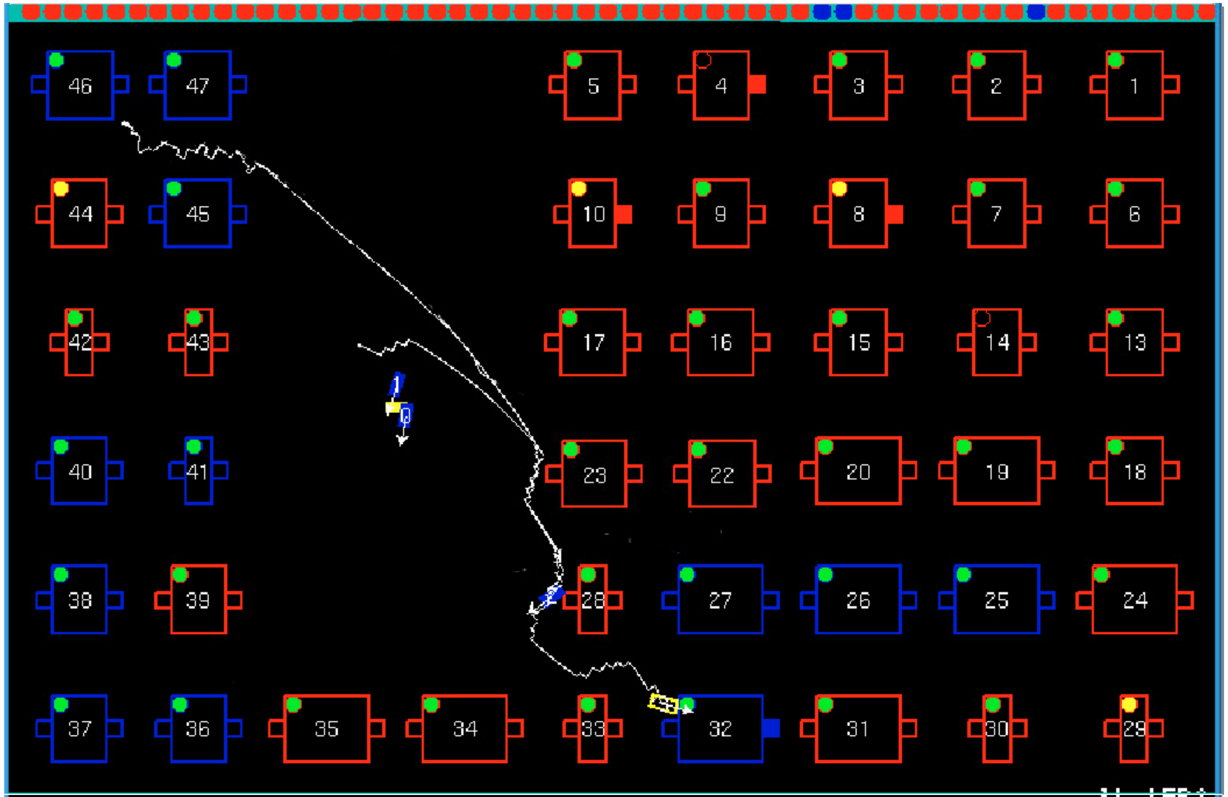
AGV No.	1	2	3	4
R×4	101	102	120	111
R×2，B R×2	165	167	52	50

限定合理的AGVは局所的目的の達成度が低い.

↓

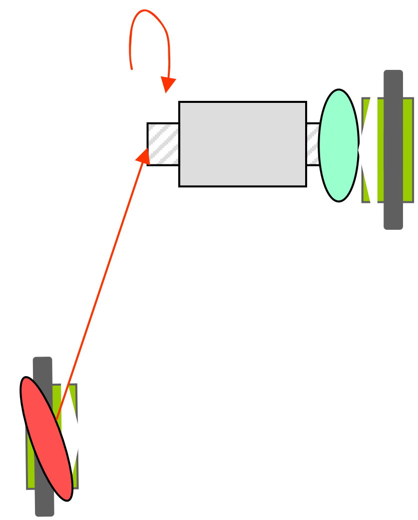
システムのレベルで観れば，利他性が創発している.

時間的競合の回避



合理的AGV 4台の場合

合理的AGV 2台，
限定合理的AGV 2台
の場合



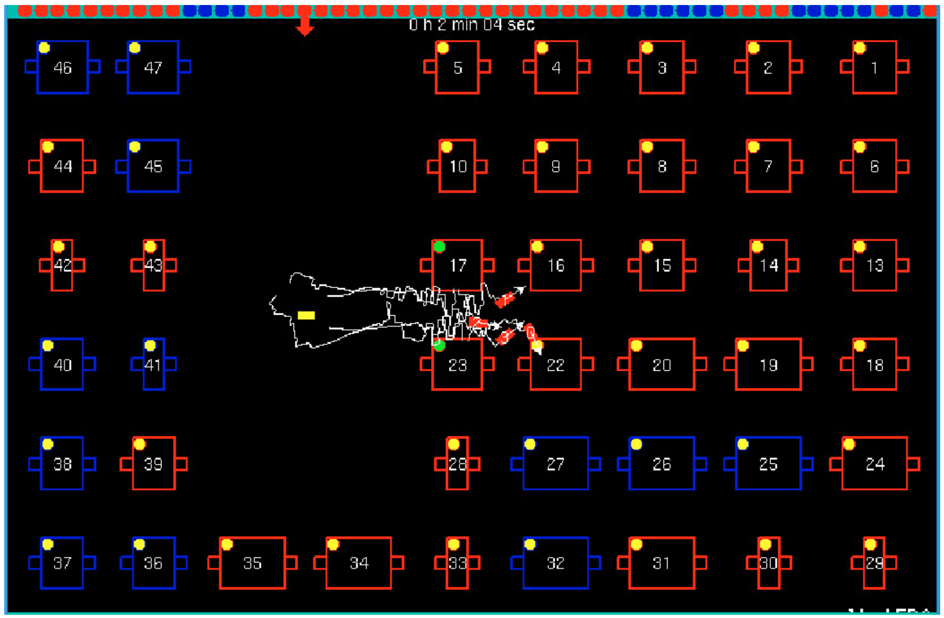
表）搬送先の機械から製品を受け取った回数

AGV No.	1	2	3	4	合計
R×4，BR×0	8	12	7	8	35
R×2，BR×2	26	29	3	2	60

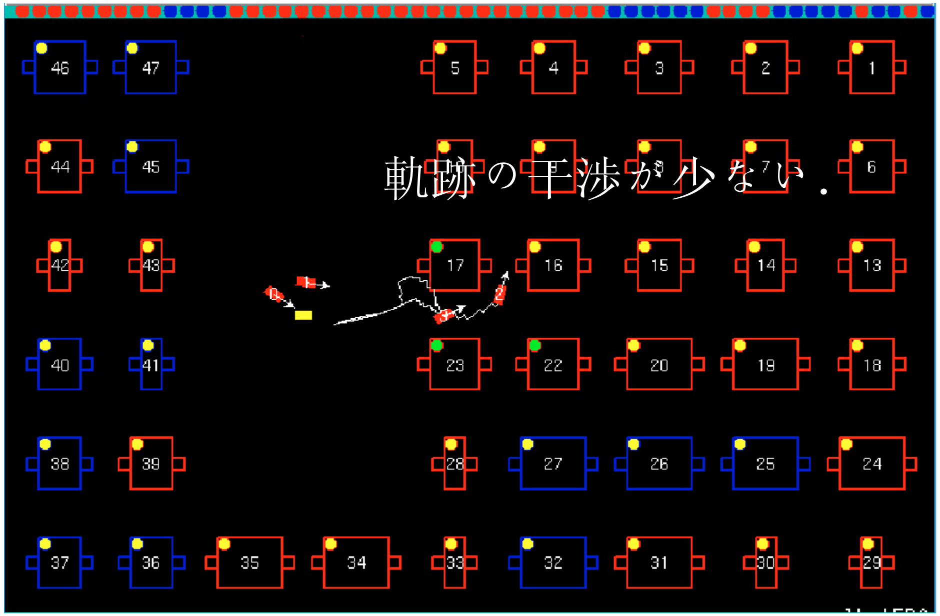
効率的な挙動

⇒ 性能の向上

空間的競合の回避



合理的AGV 4台



合理的AGV 2台，限定合理的AGV 2台

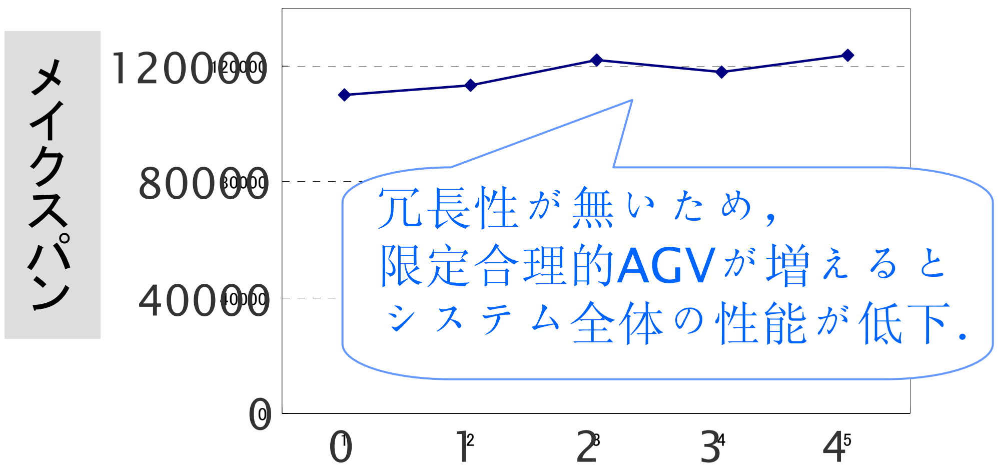
限定合理性の導入により，AGV同士の時間的競合・空間的競合が回避された．

⇒ システムの性能向上

実験結果：(Type-3)の導入

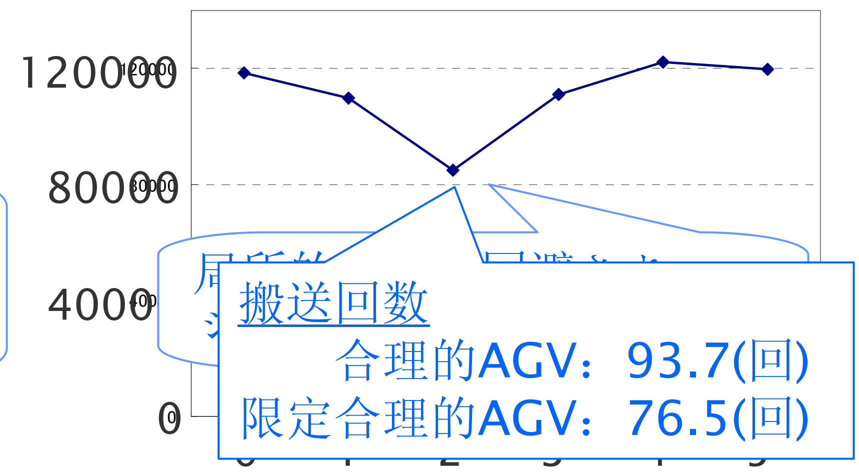
(Type-2)：働きすぎると怠ける

AGV台数：4台のとき



限定合理的AGVの台数(4台中)

AGV台数：5台のとき



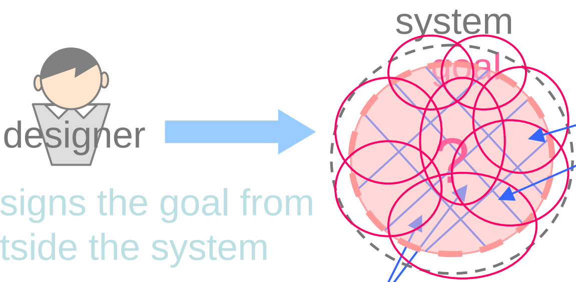
限定合理的AGVの台数(5台中)

システムの性能向上．ただし，合理的AGVと限定合理的AGVの差が少ない．

環境や他のAGVの状況に応じて，局所的競合が適応的に回避されている

Introduction-3

Artifactual system



designs the goal from outside the system

assign to multiple agents as local goals by taking into account limitation of ability

Distributed problem solving

Emergent Synthetic approach

Redundancy

dilemma

$$G \neq \bigcup_{k=1}^{n} L_k$$

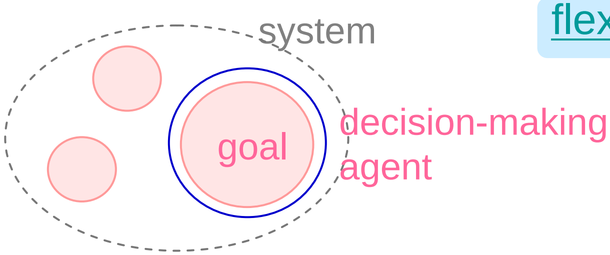
(G: global goal, L_k: local goal (k=1, …, n))

⇒ **local competition or conflict**

Existing effective approaches:

1. introducing a superior agent who can command other agents;
2. providing rules to avoid local competition in advance;
3. giving an incentive for attain the system goal to each agent.

Social system

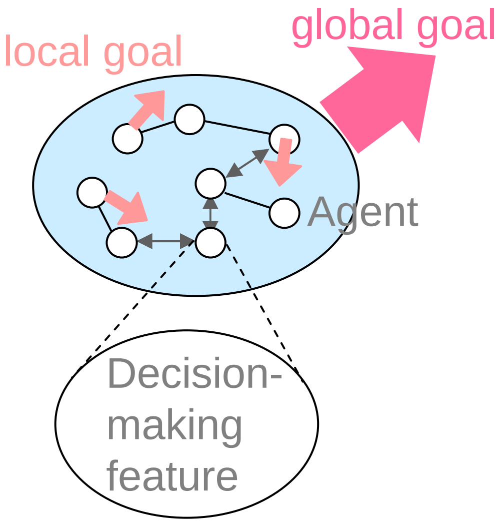


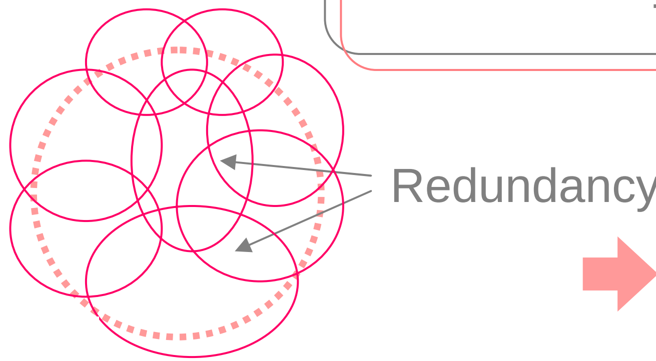
flexible, adaptive, robust

- avoidance of competition or conflict
- resolution of the dilemma
- **role-sharing**
- **altruism**

Bounded Rationality

Specification of Target Problems





The sum of the local goals of each agents
≠
The global goal

→ local competition or conflict

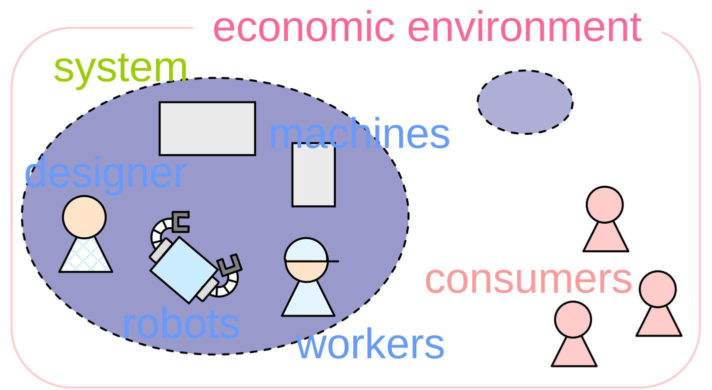
<u>Existing effective methods:</u>

- introducing a superior agent who can command other agents
- forcing goals to be shared among agents
- distributing rewards of attaining the system goal among all agents

…It is difficult to
- introduce a superior agents
- perceive information of the whole system or other agents

Introducing bounded rationality decreases the amount of information that is necessary for the agents to make decisions.

Introduction



Manufacturing systems

- consist of various agents
- achieve the goal: efficient production
- are placed in complex and dynamic environment
- have to respond to diverse requests

→ Decision-making under incomplete conditions

Optimality < Adaptivity, Robustness

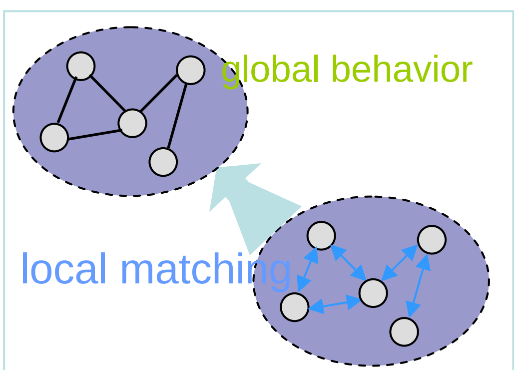
~~Top-down approach~~

Bottom-up approach
Agent-based approach

Biological Manufacturing Systems (BMS) [Ueda 1987]

BMS is a next-generation manufacturing system model, which adapts to unpredictable changes in complex environments, based on biologically-inspired ideas such as self-organization.

Self-organization-based BMS



Production process emerges, as global behavior, from local interactions among the system elements.

Local interaction: matching between the capabilities of the machines and the requirements of the jobs.

Decision Making agents = AGVs

Introduce *bounded rationality*