CIFMA 2024 — 5 November 2024, Aveiro, Portugal

Cognitive Aspects in the Formal Modelling of Multi-party Human-computer Interactionr

Antonio Cerone and *Olzhas Zhangeldinov*
antonio.cerone.@nu.edu.kz olzhas.zhangeldinov@nu.edu.kz

Department of Computer Science, SEDS, Nazarbayev University, Astana, Kazakhstan

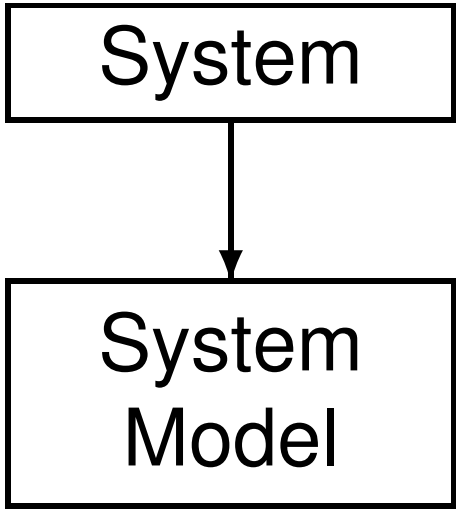
Background and Motivation

- What are Formal Methods?
- Why to use Formal Methods in HCI?
- What is Multi-party HCI?

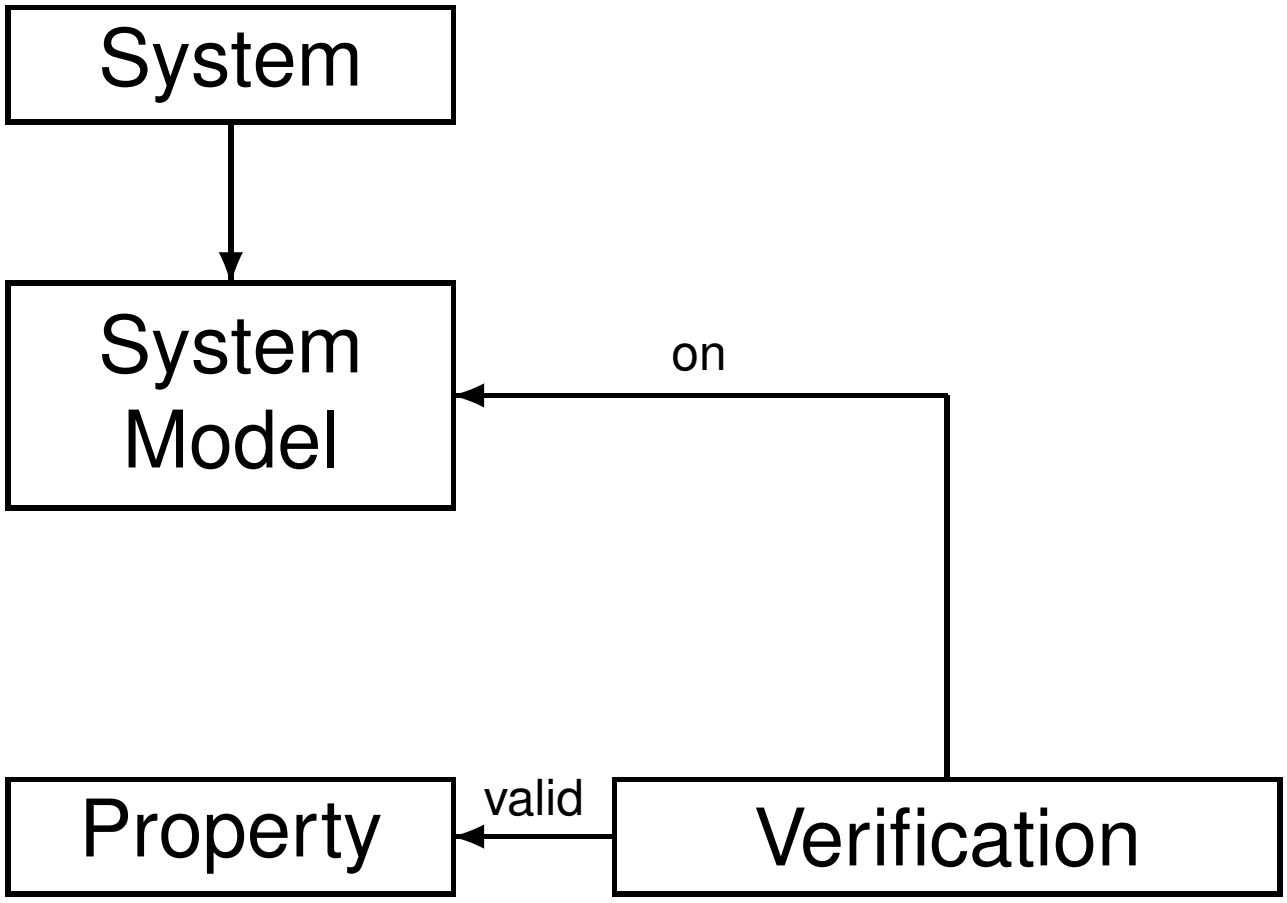
Formal Methods

System

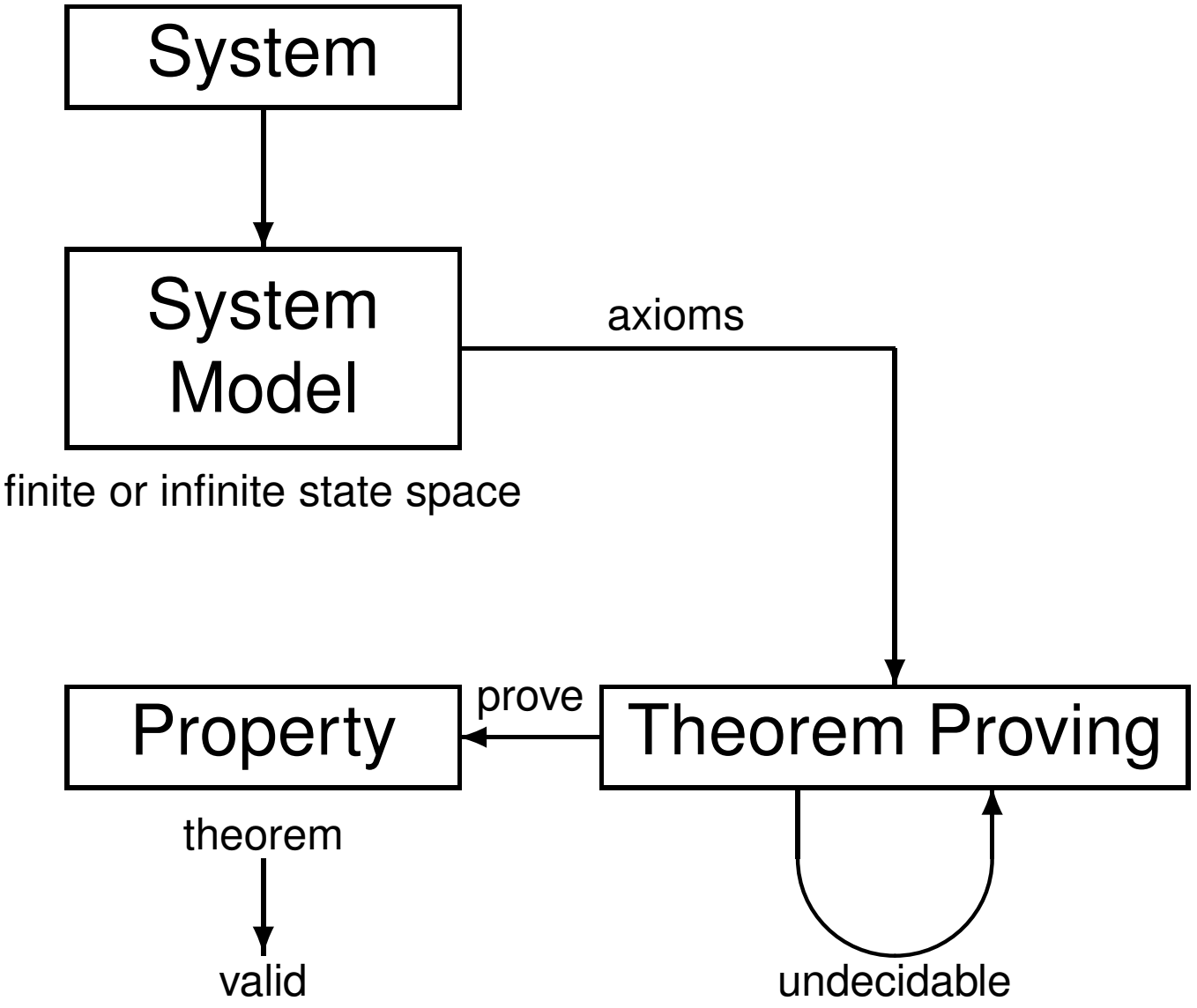
Formal Methods



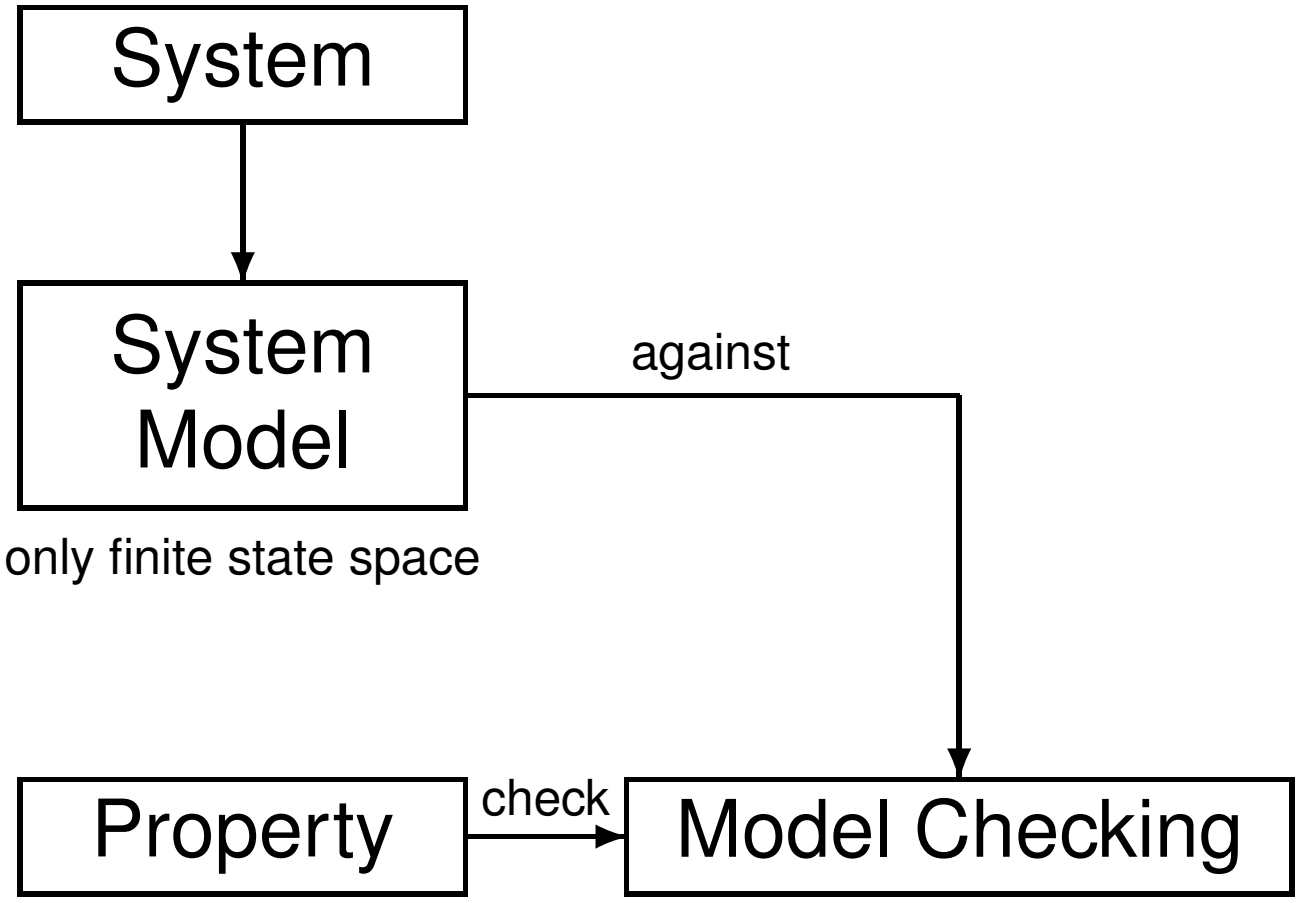
Formal Methods



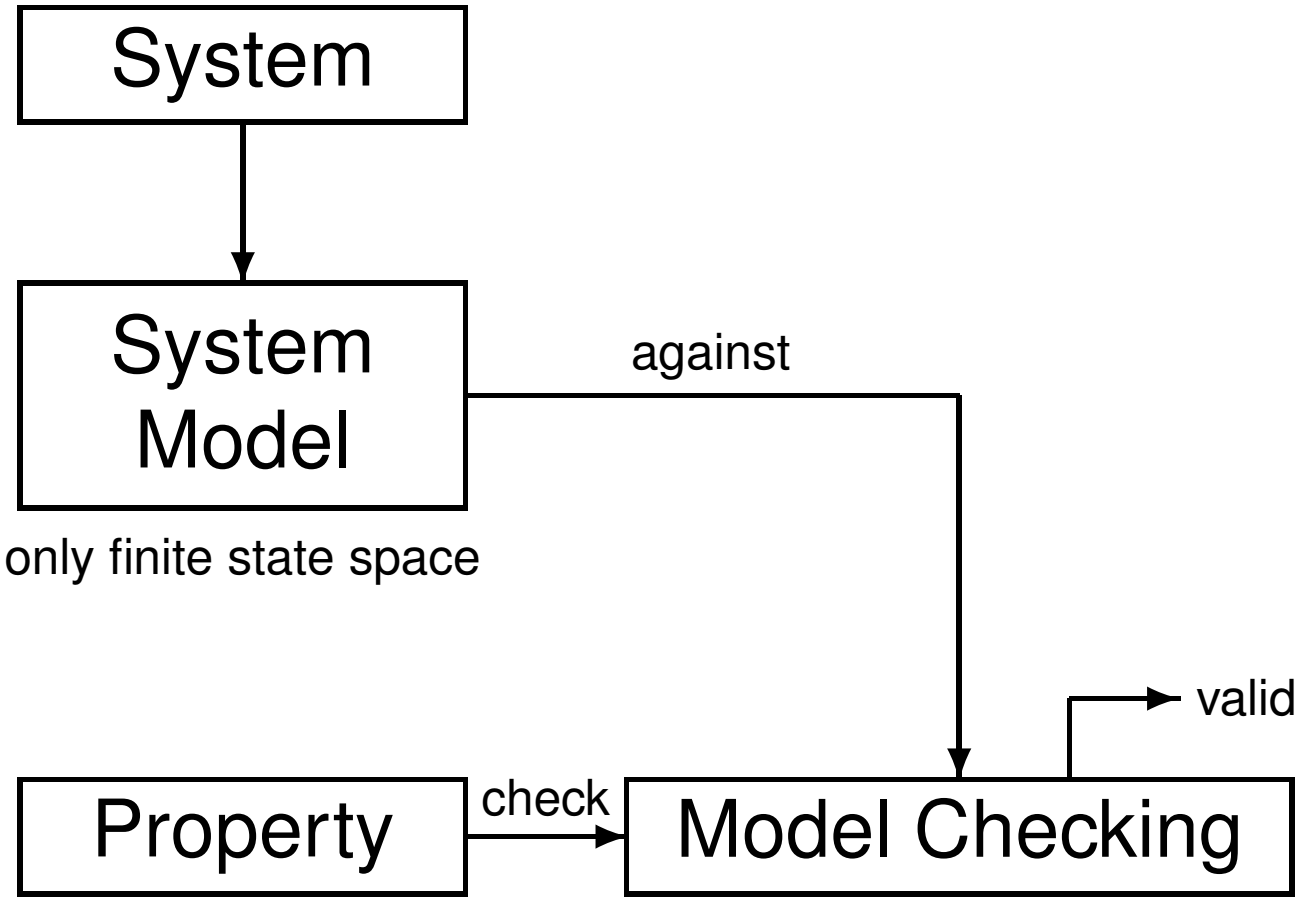
Formal Methods



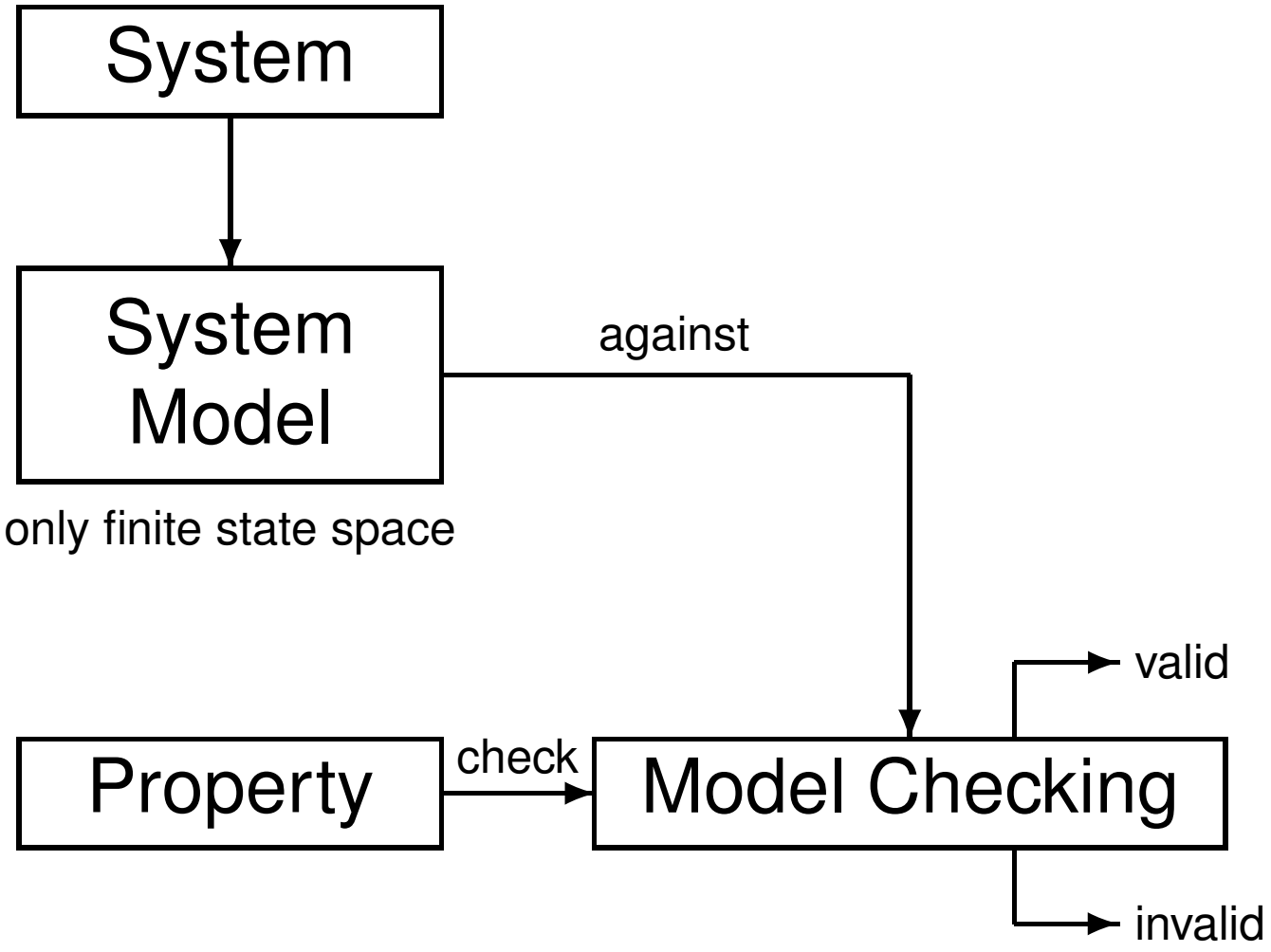
Formal Methods



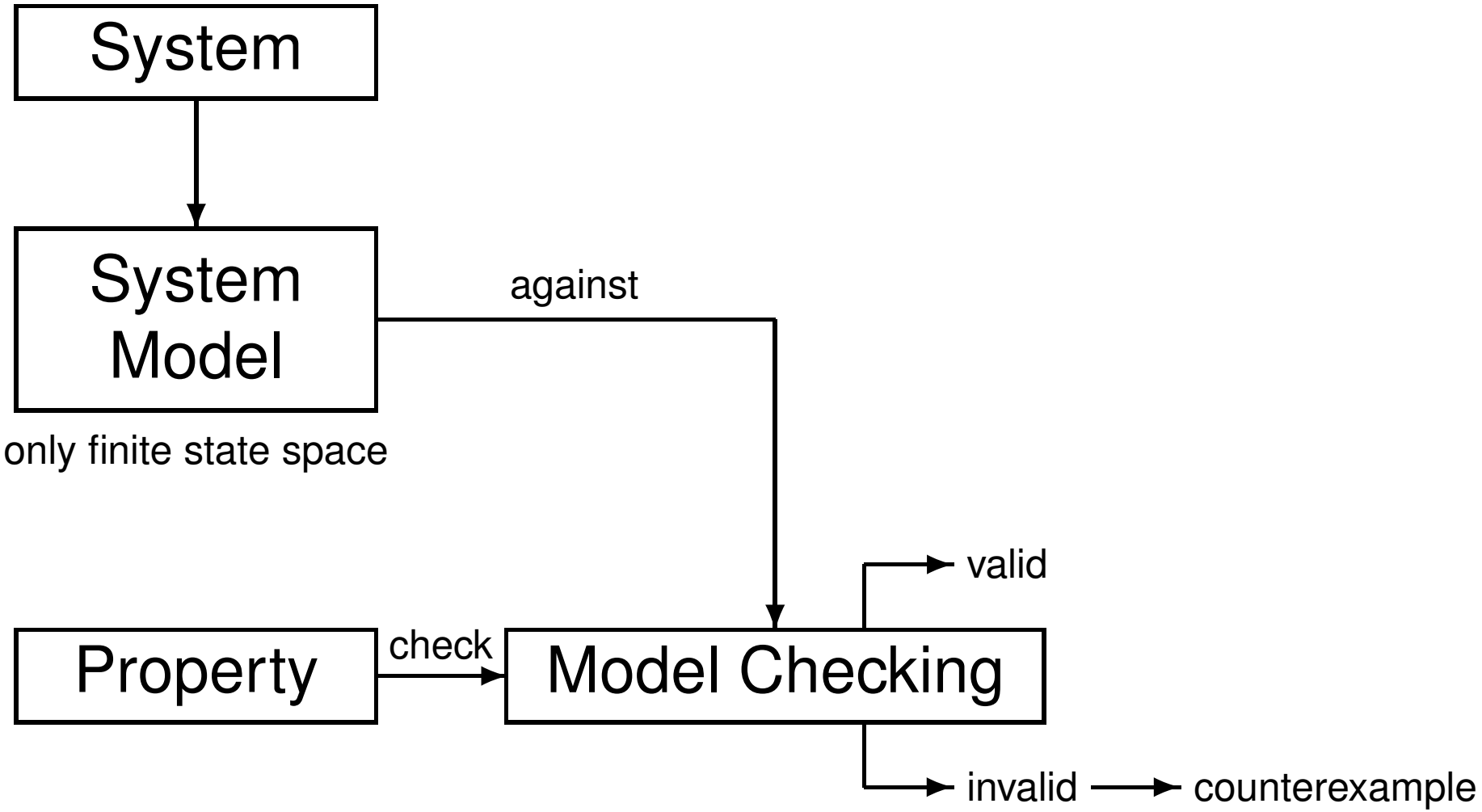
Formal Methods



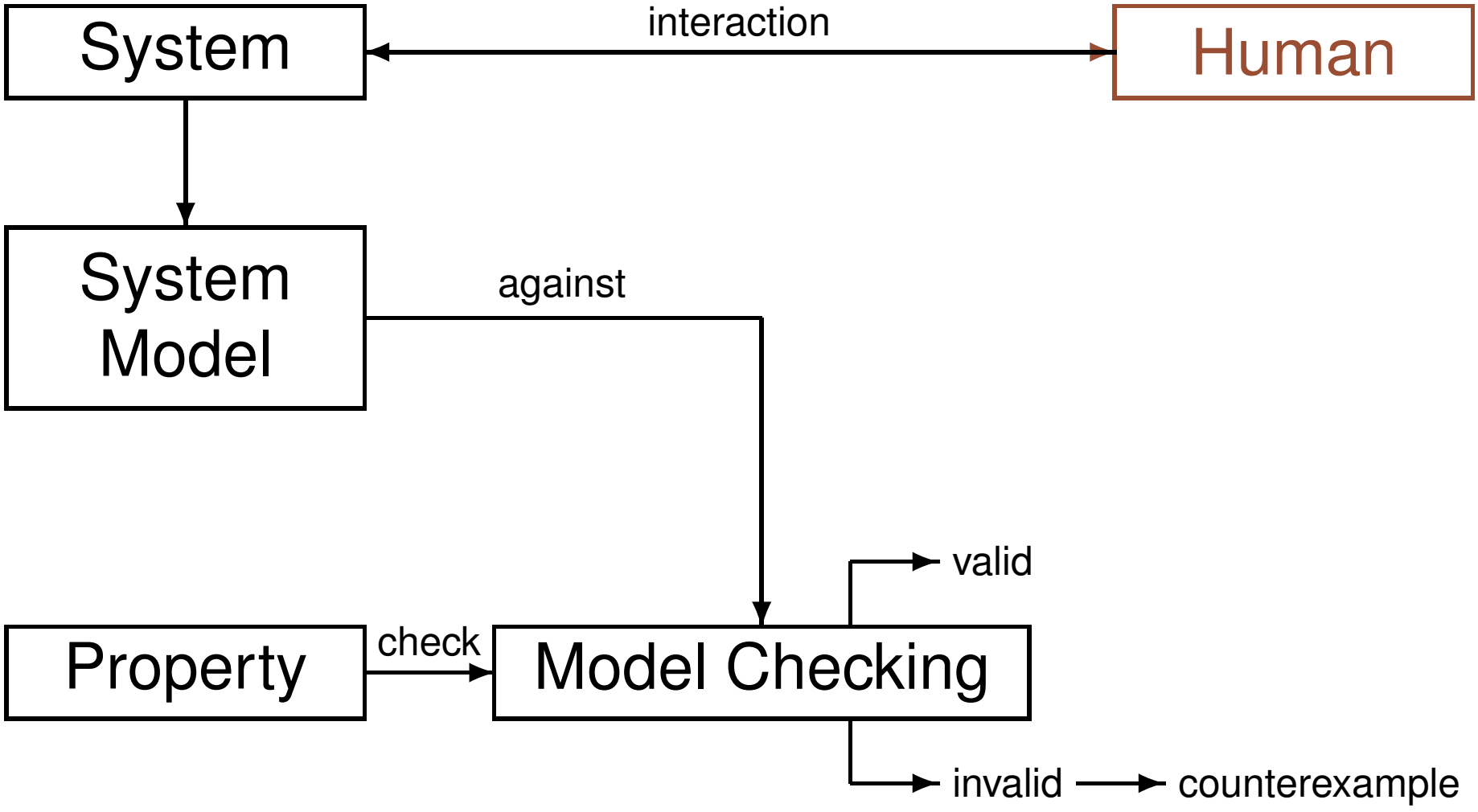
Formal Methods



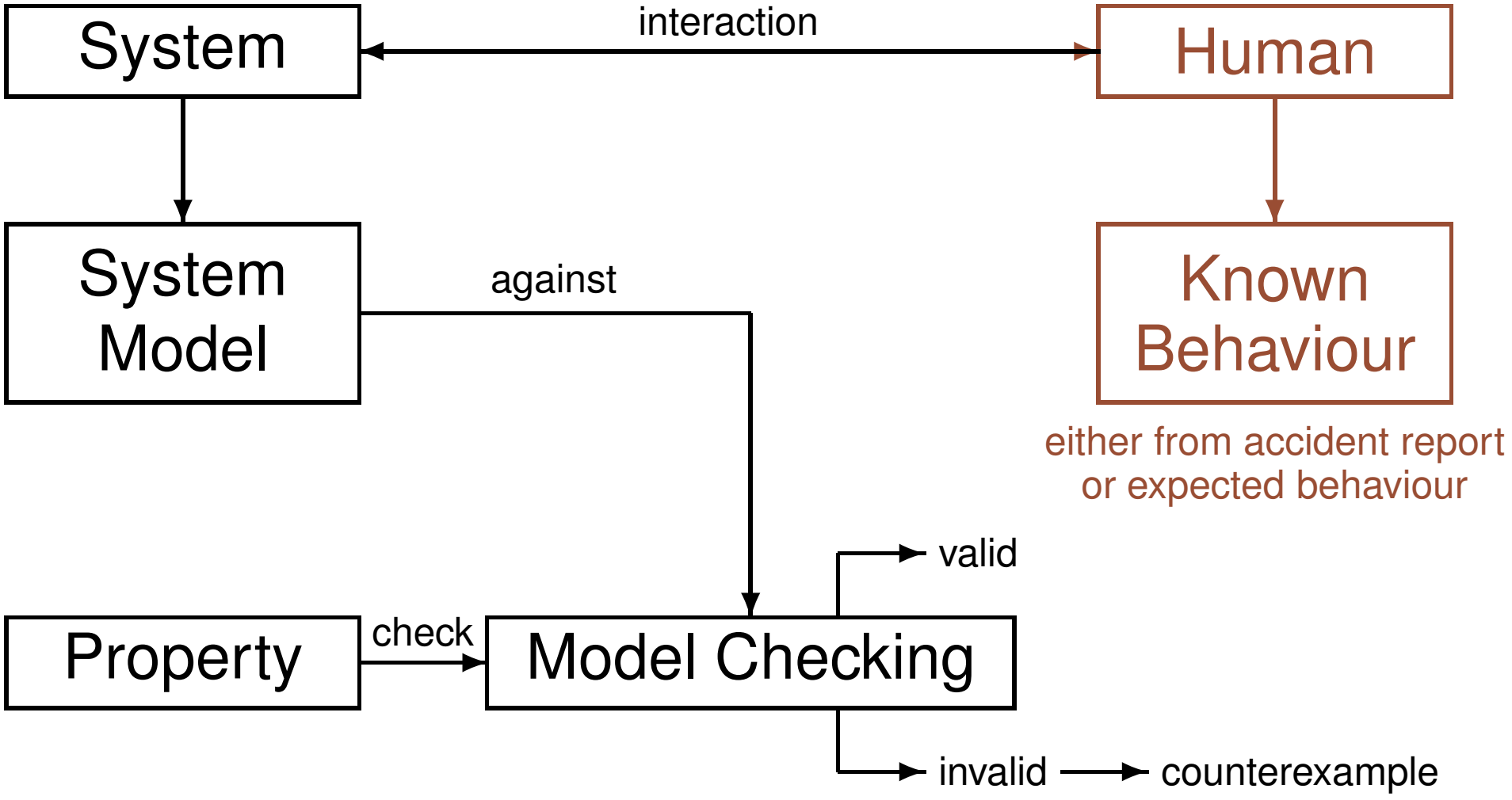
Formal Methods



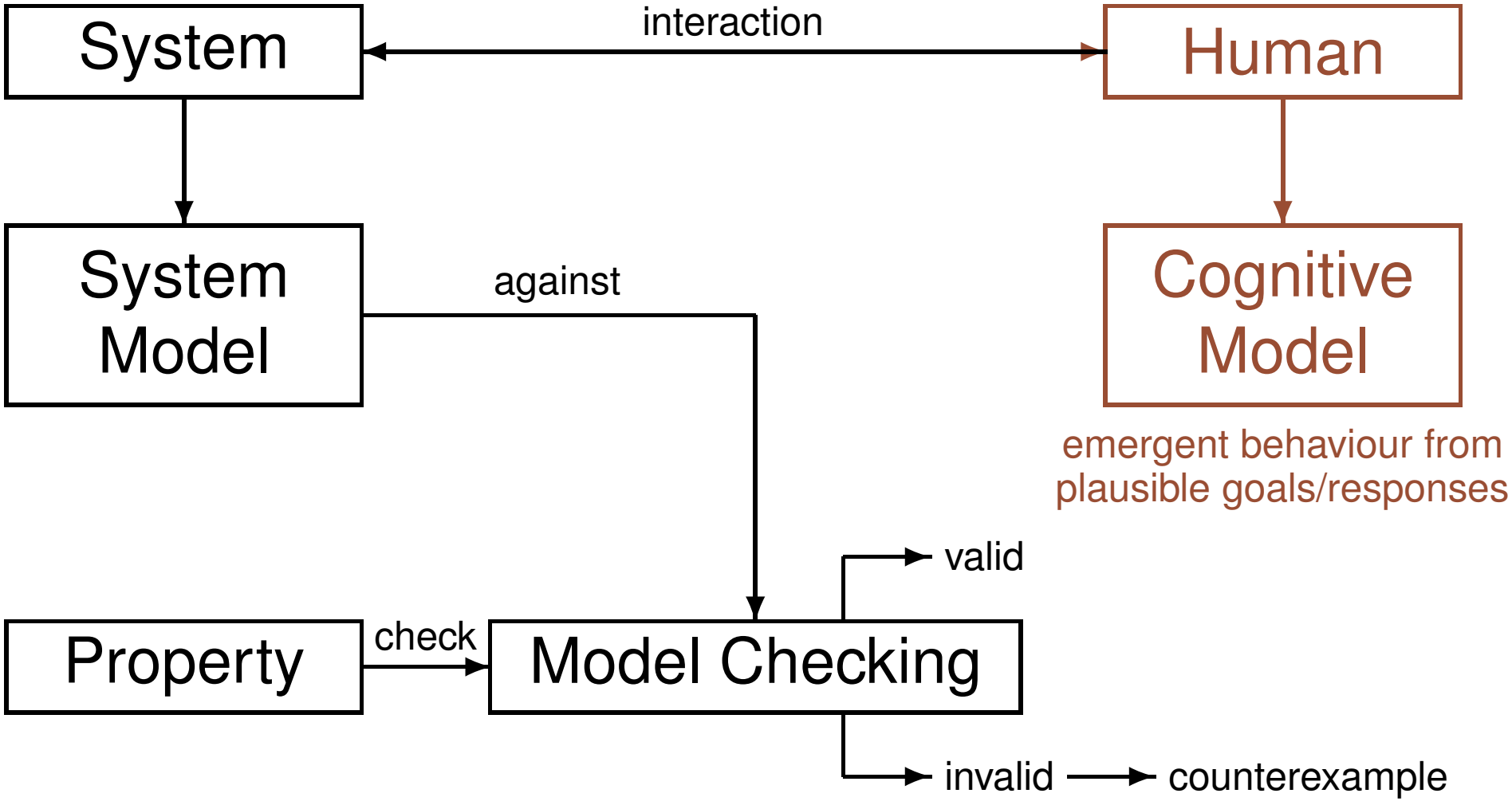
Why to use Formal Methods in HCI?



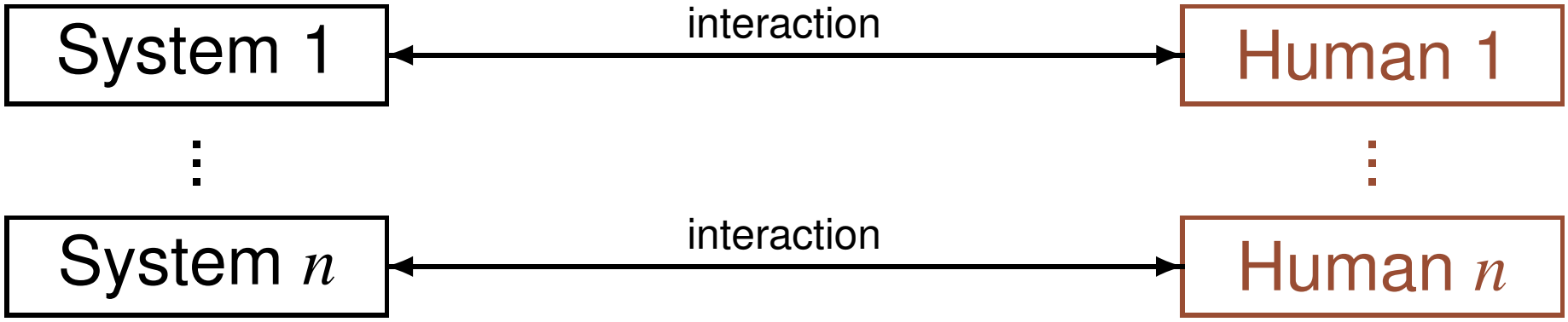
Why to use Formal Methods in HCI?



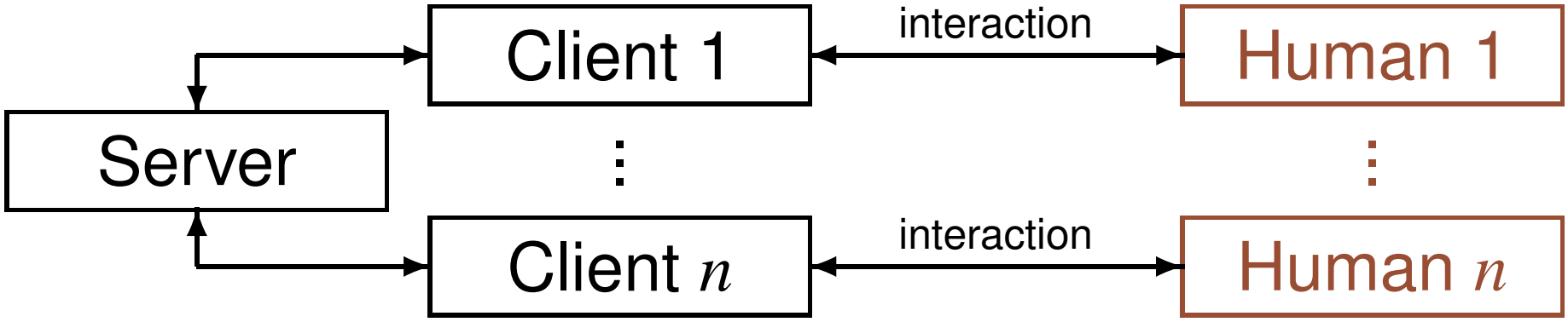
Why to use Formal Methods in HCI?



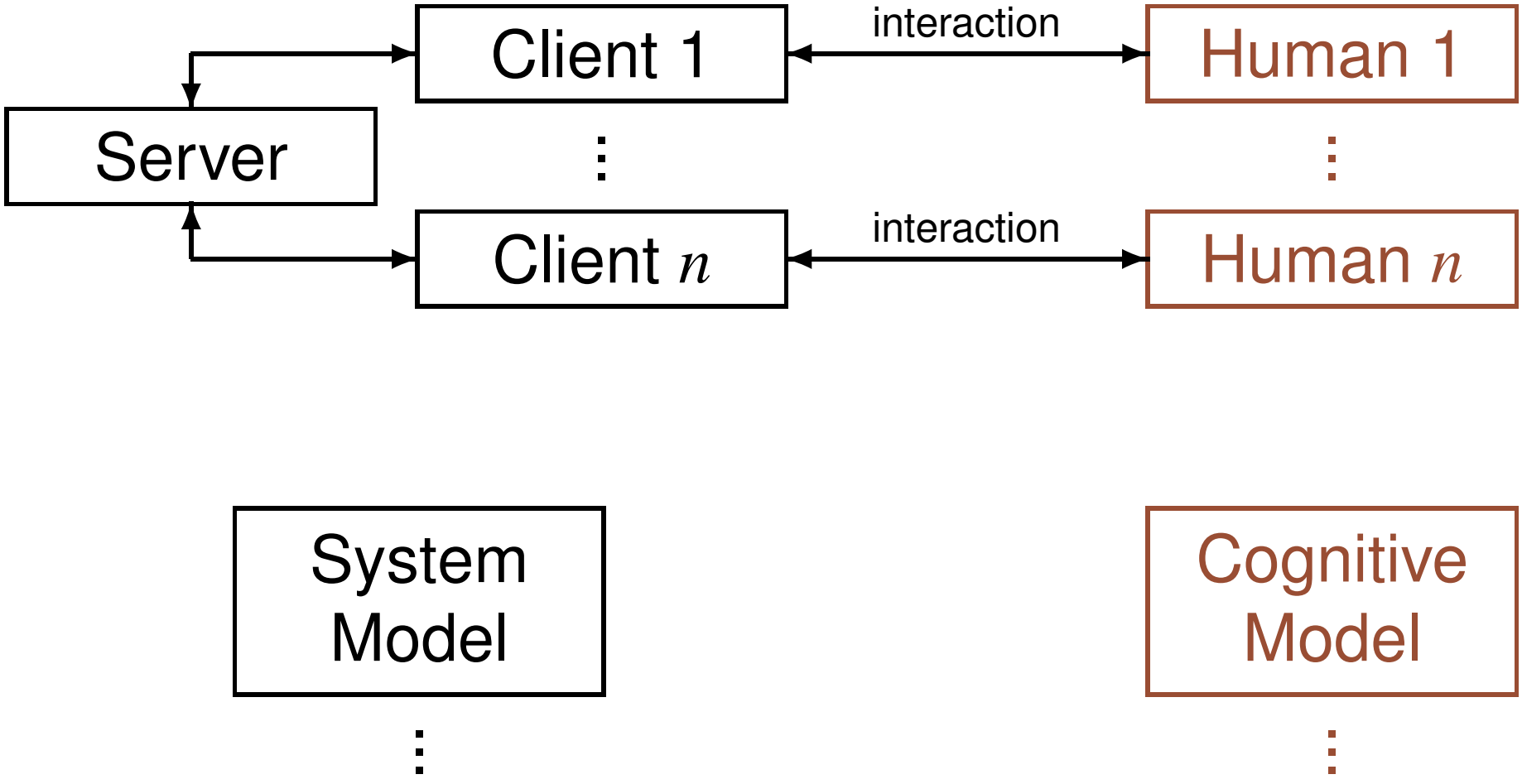
What is Multi-party HCI?



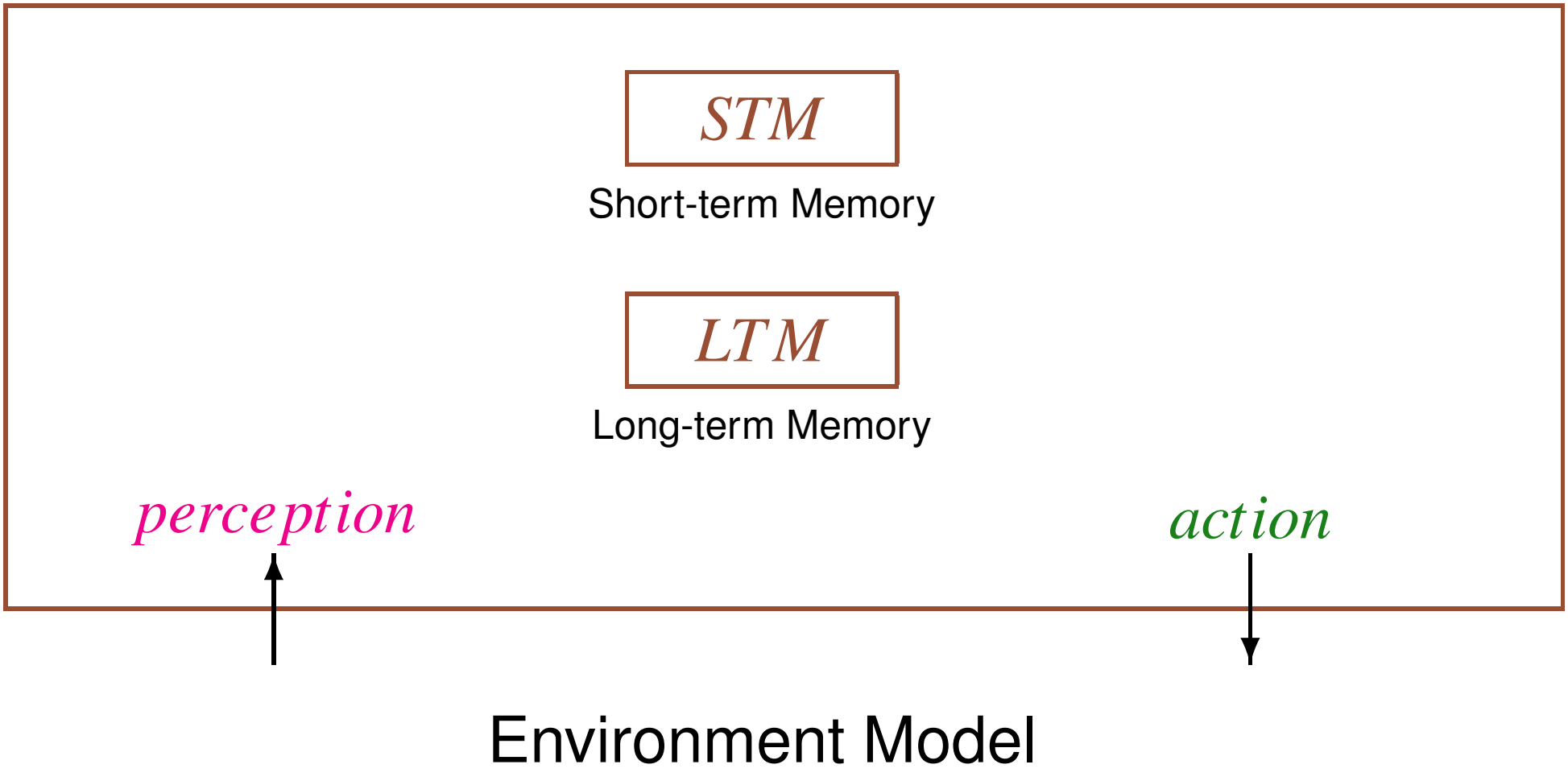
What is Multi-party HCI?



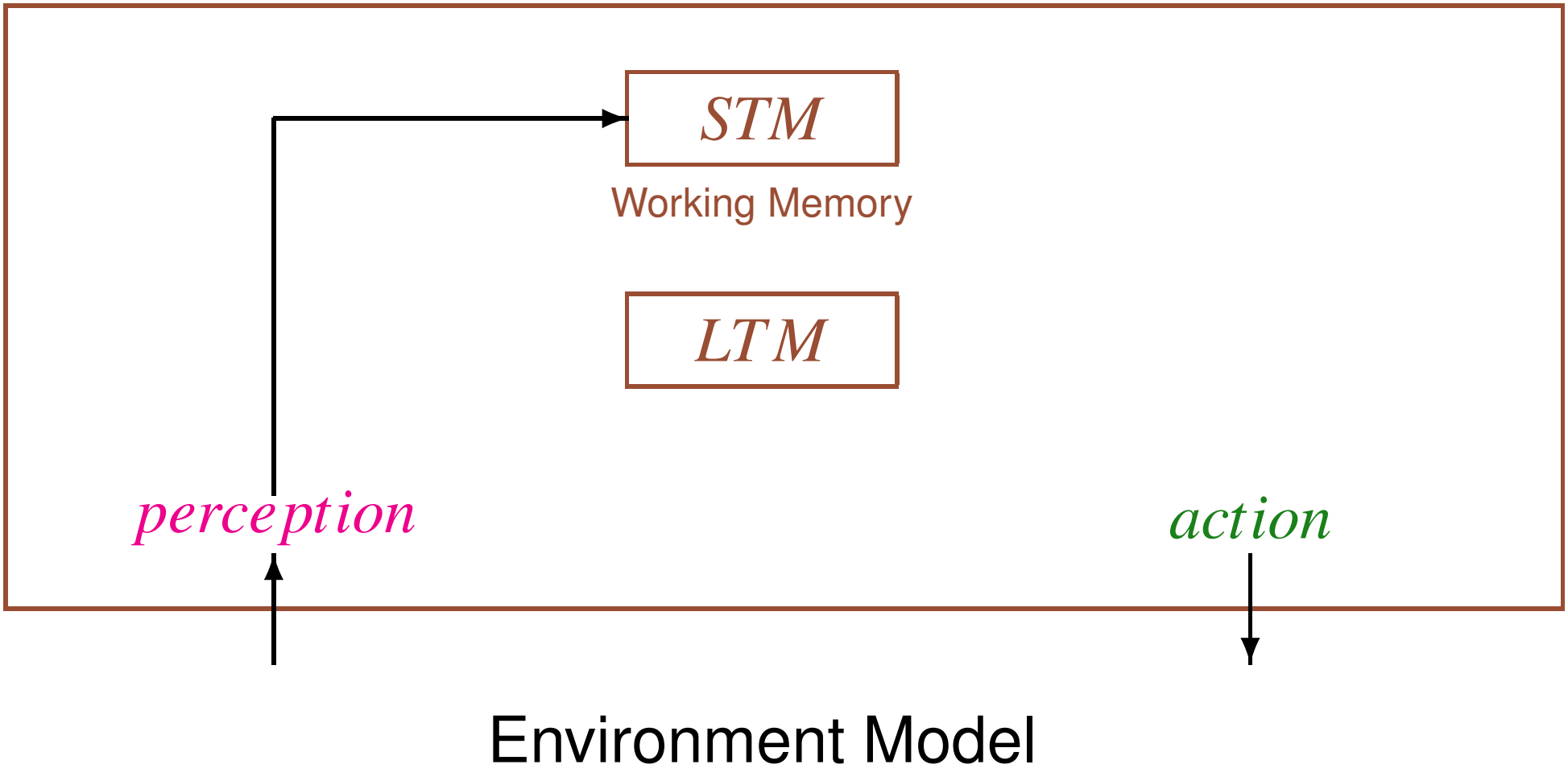
What is Multi-party HCI?



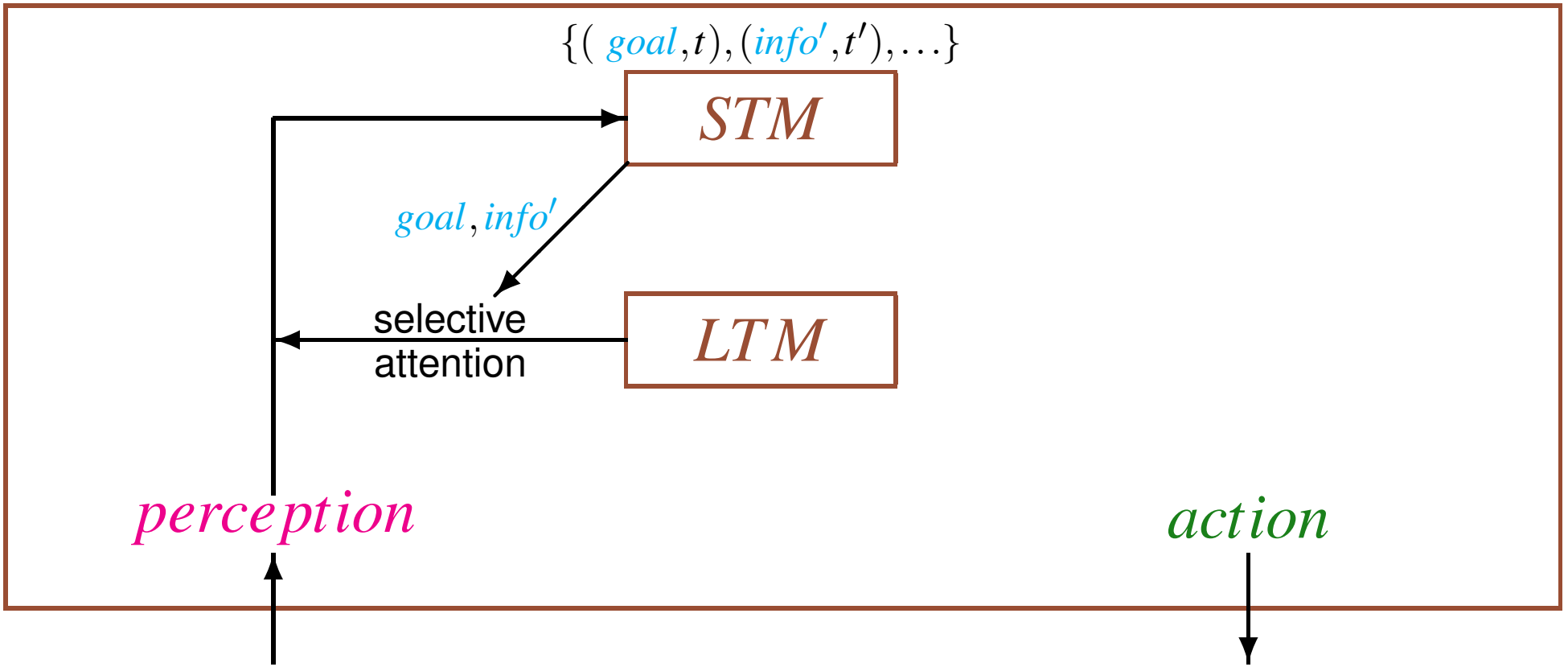
User Cognitive Model (UCM)



User Cognitive Model (UCM)

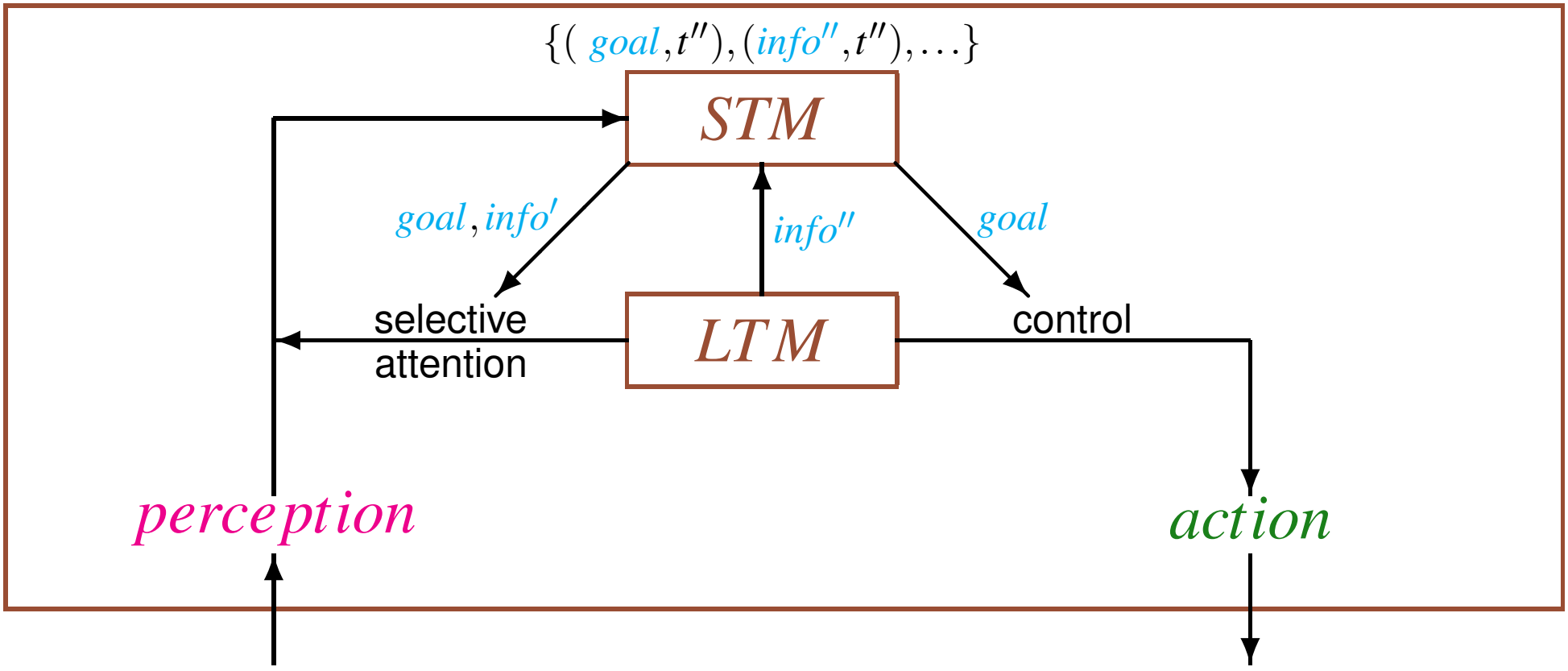


User Cognitive Model (UCM)



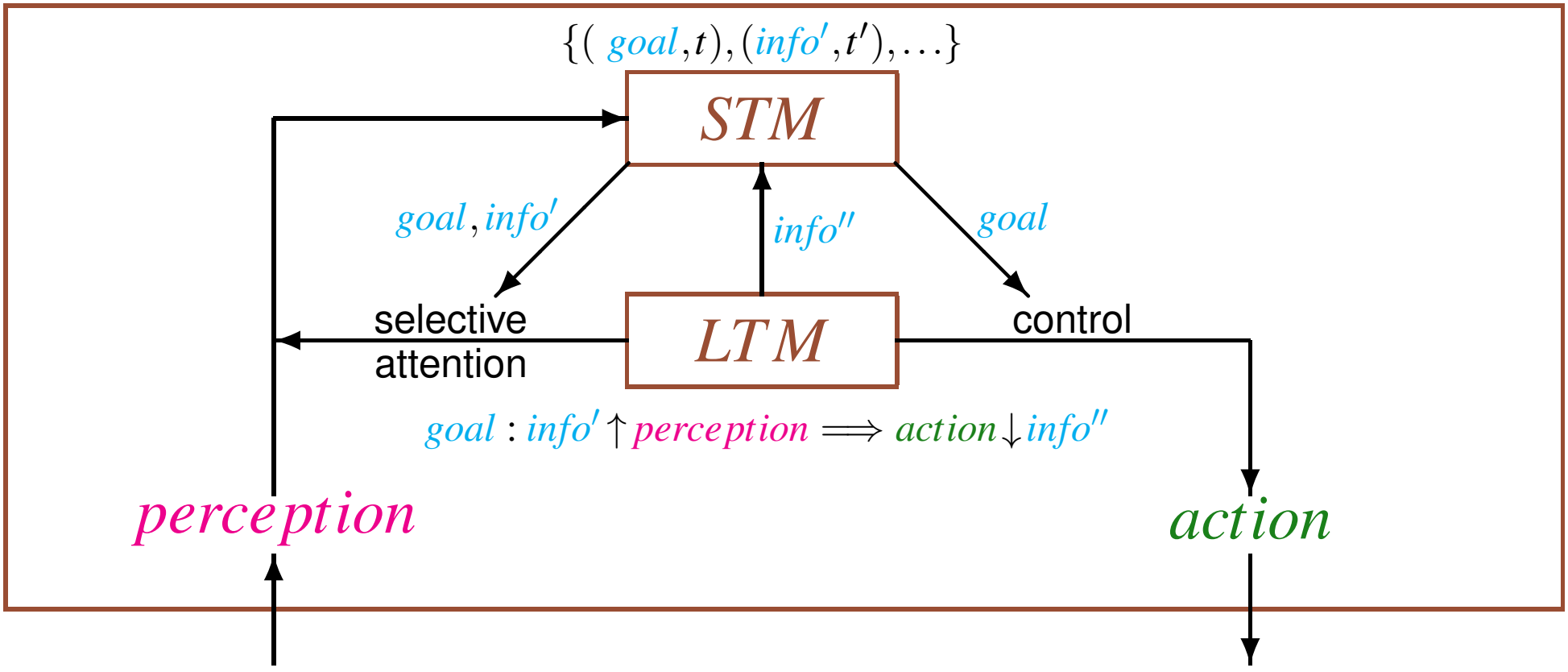
Environment Model

User Cognitive Model (UCM)



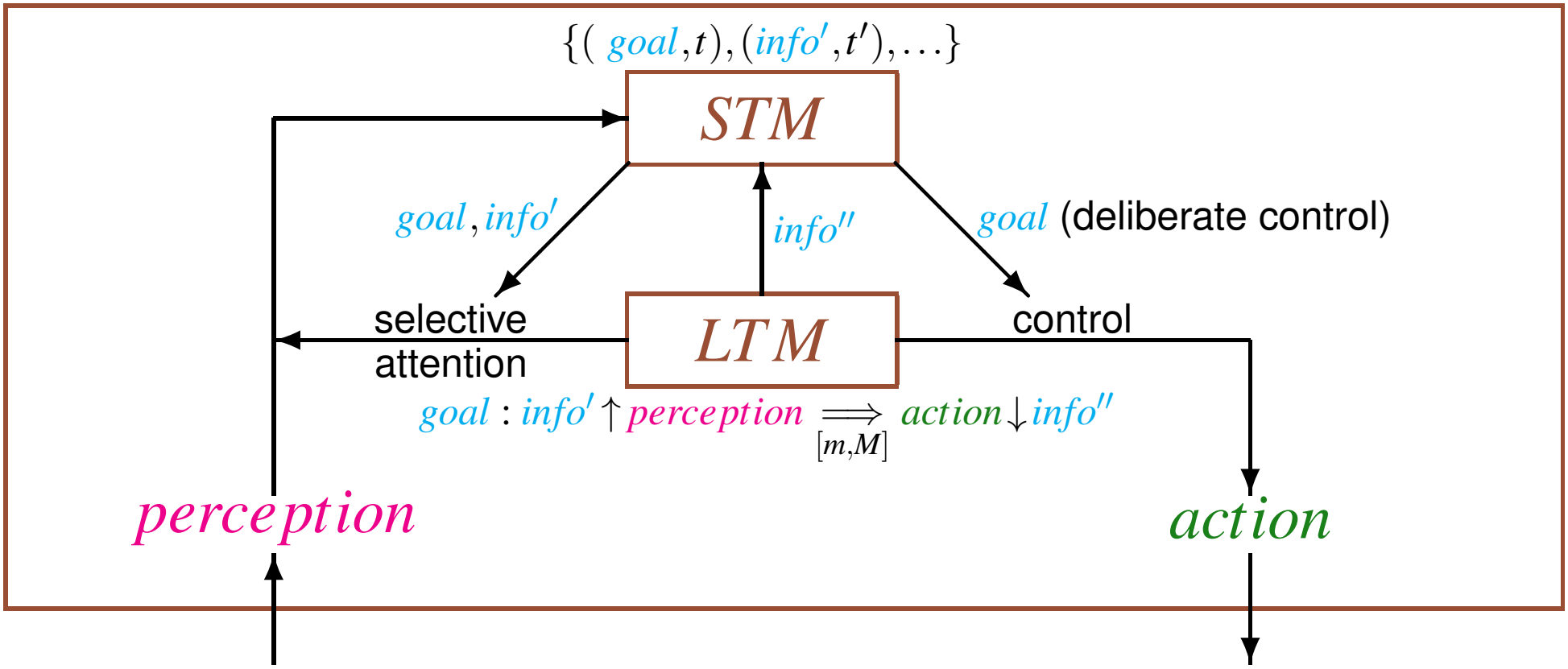
Environment Model

User Cognitive Model (UCM)



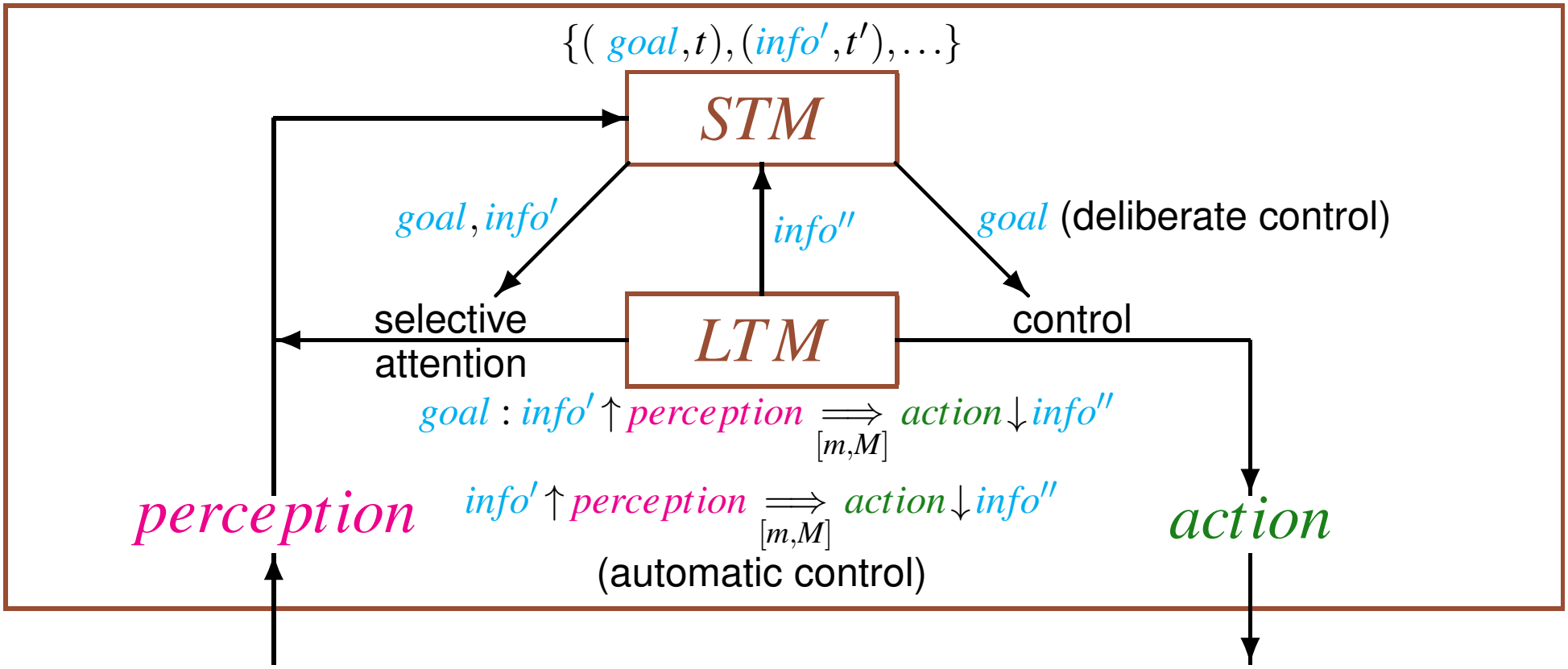
Environment Model

User Cognitive Model (UCM)



Environment Model

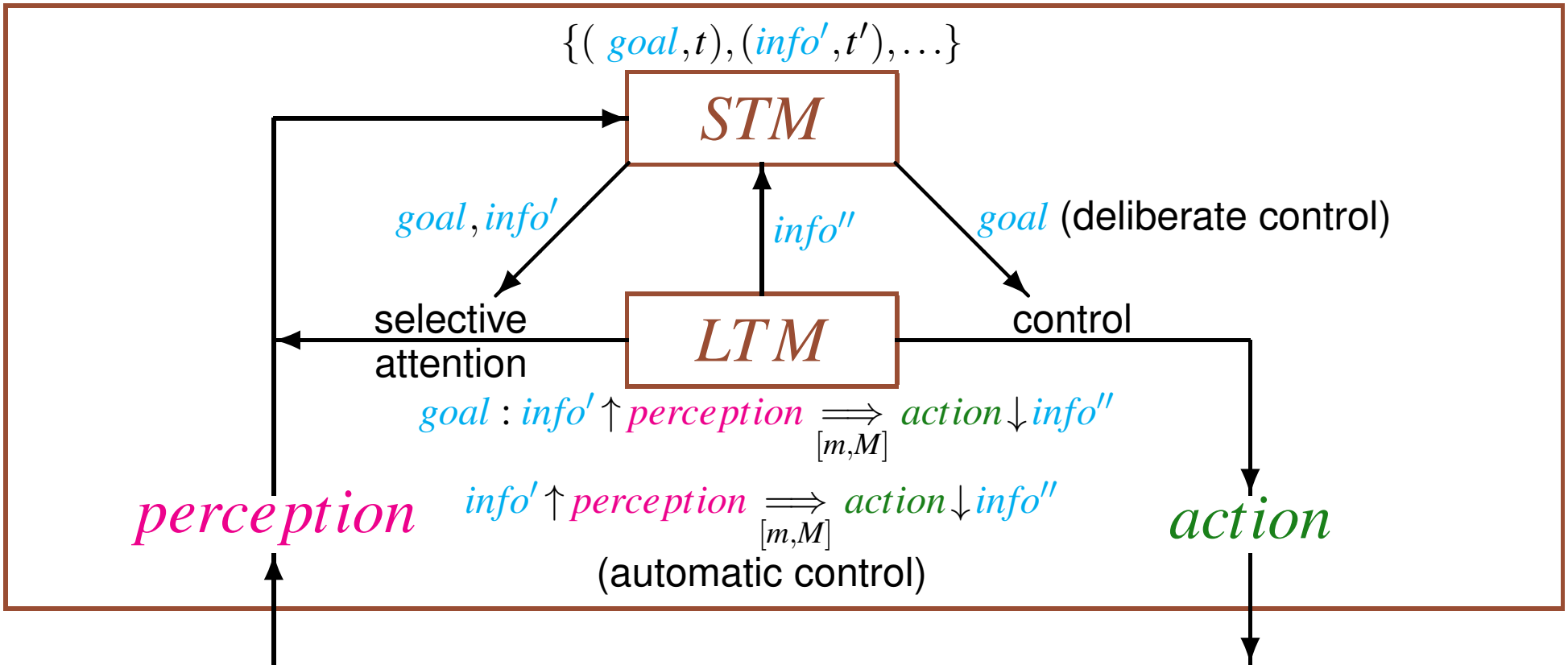
User Cognitive Model (UCM)



Environment Model

User Cognitive Model (UCM)

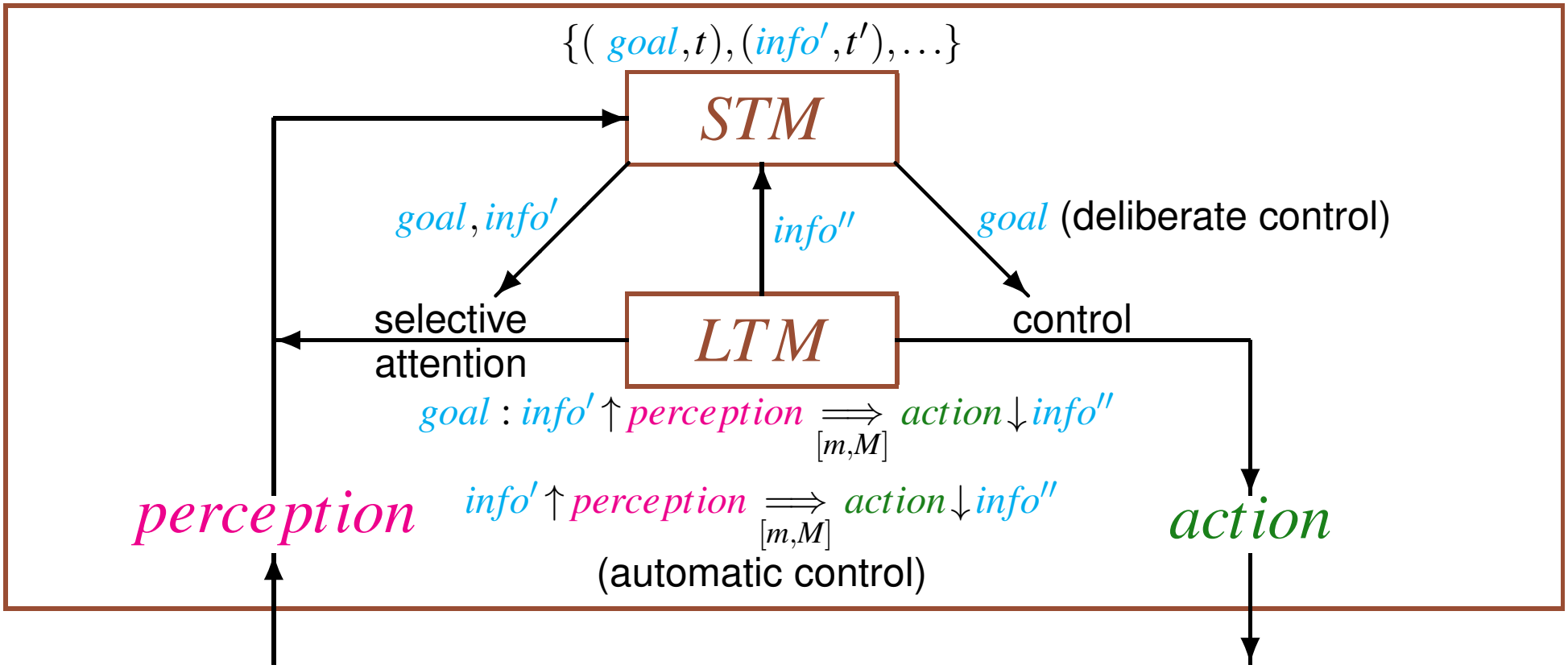
Behaviour and Reasoning Description Language (BRDL)



Environment Model

User Cognitive Model (UCM)

Behaviour and Reasoning Description Language (BRDL)



Environment Model
(Client Model)

Example: Student UCM in BRDL

$$\uparrow emptyPage \underset{[100,300]}{\Longrightarrow} refresh\downarrow$$

$$goal(enrolled) : \uparrow available \underset{[100,300]}{\Longrightarrow} enrol\downarrow$$

$$goal(enrolled) : \uparrow enrolled \underset{[100,300]}{\Longrightarrow} \downarrow enrolled$$

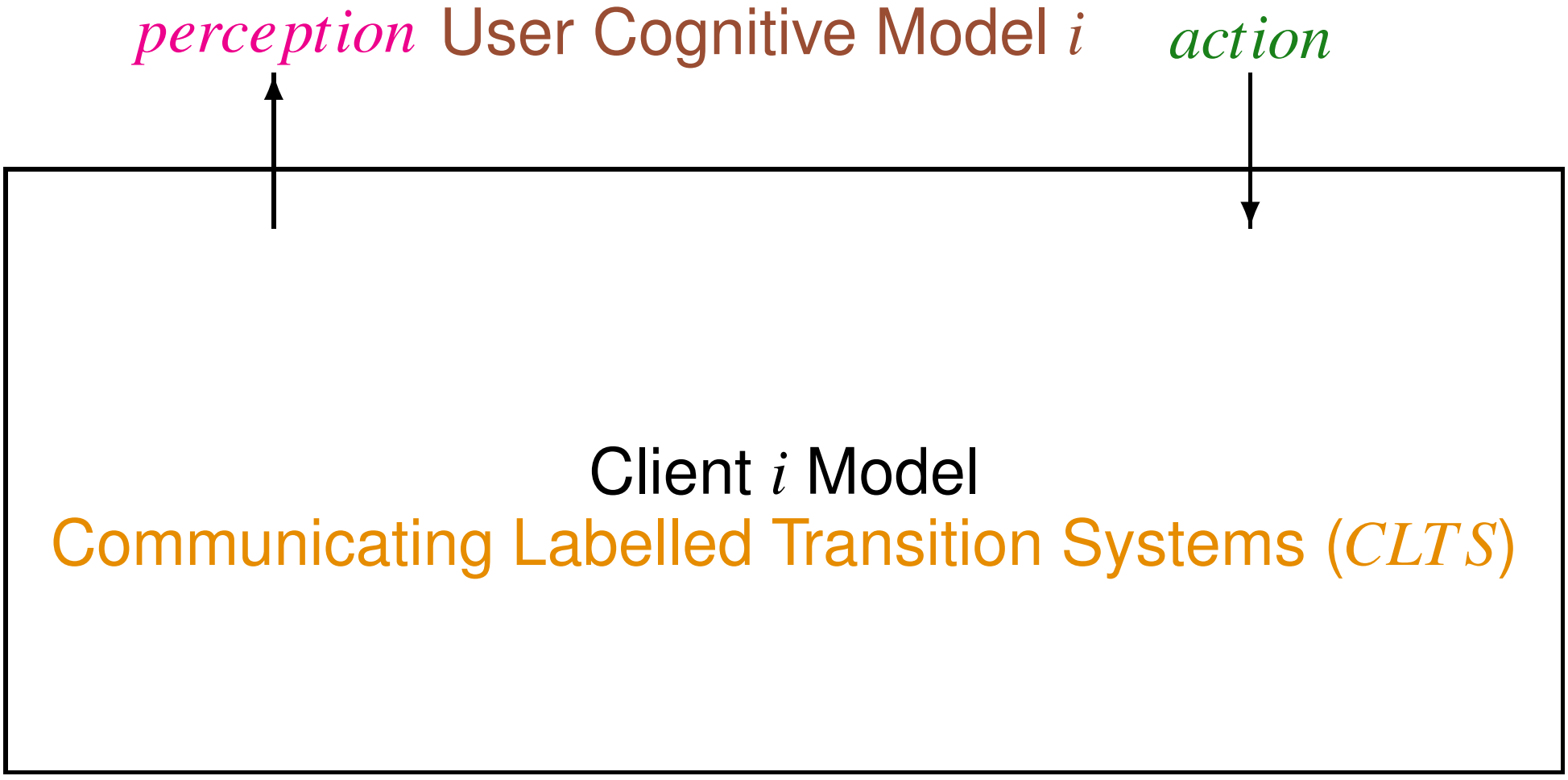
$$goal(enrolled) : \ enrolled\uparrow \underset{[100,300]}{\Longrightarrow} proceed\downarrow enrolled$$

$$goal(noLab) : \uparrow chooseLab \underset{[100,300]}{\Longrightarrow} proceed\downarrow$$

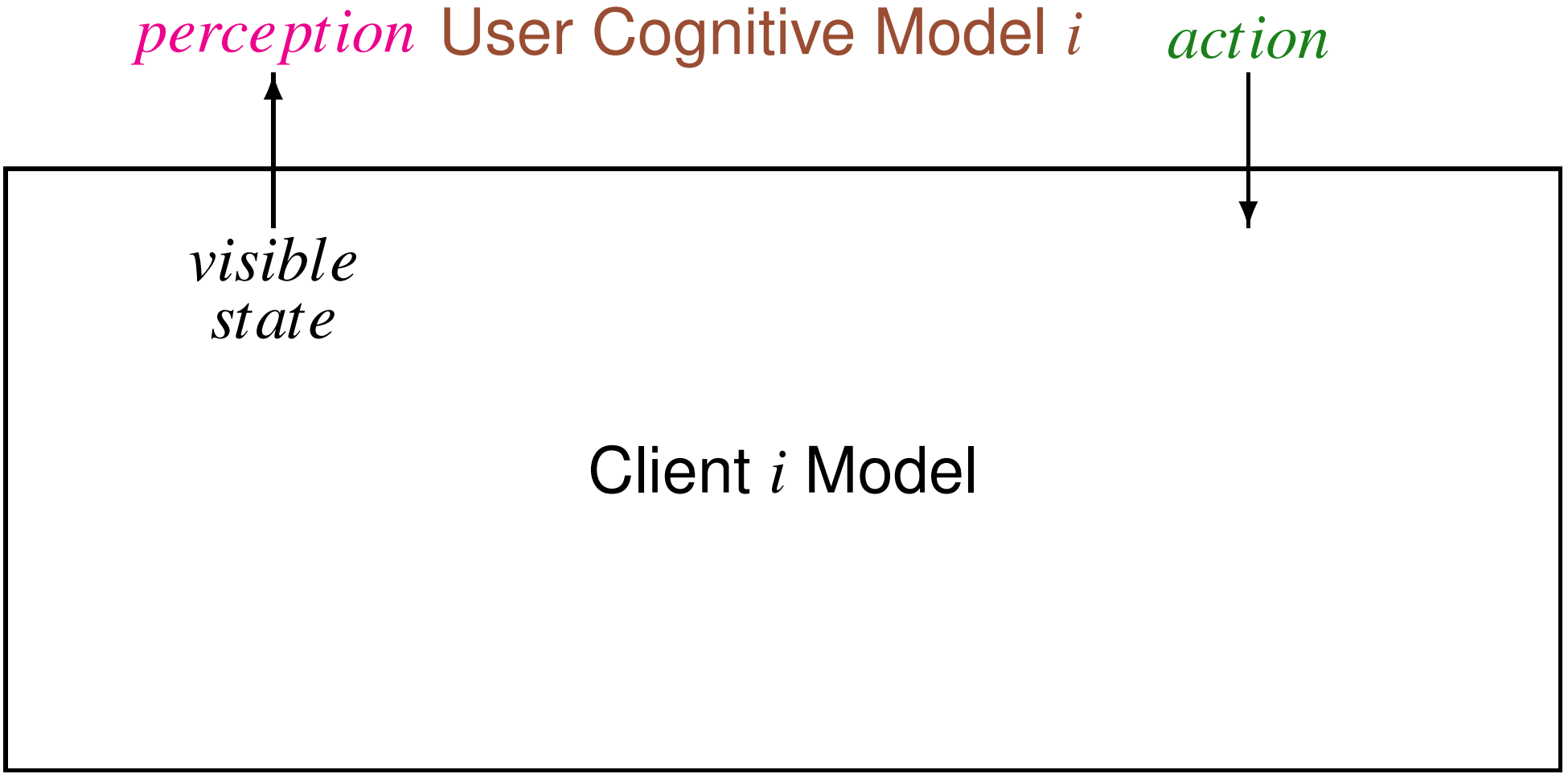
$$goal(noLab) : \uparrow noLab \underset{[100,300]}{\Longrightarrow} \downarrow noLab$$

$$goal(registerLab) : \uparrow chooseLab \underset{[100,300]}{\Longrightarrow} registerLab\downarrow$$

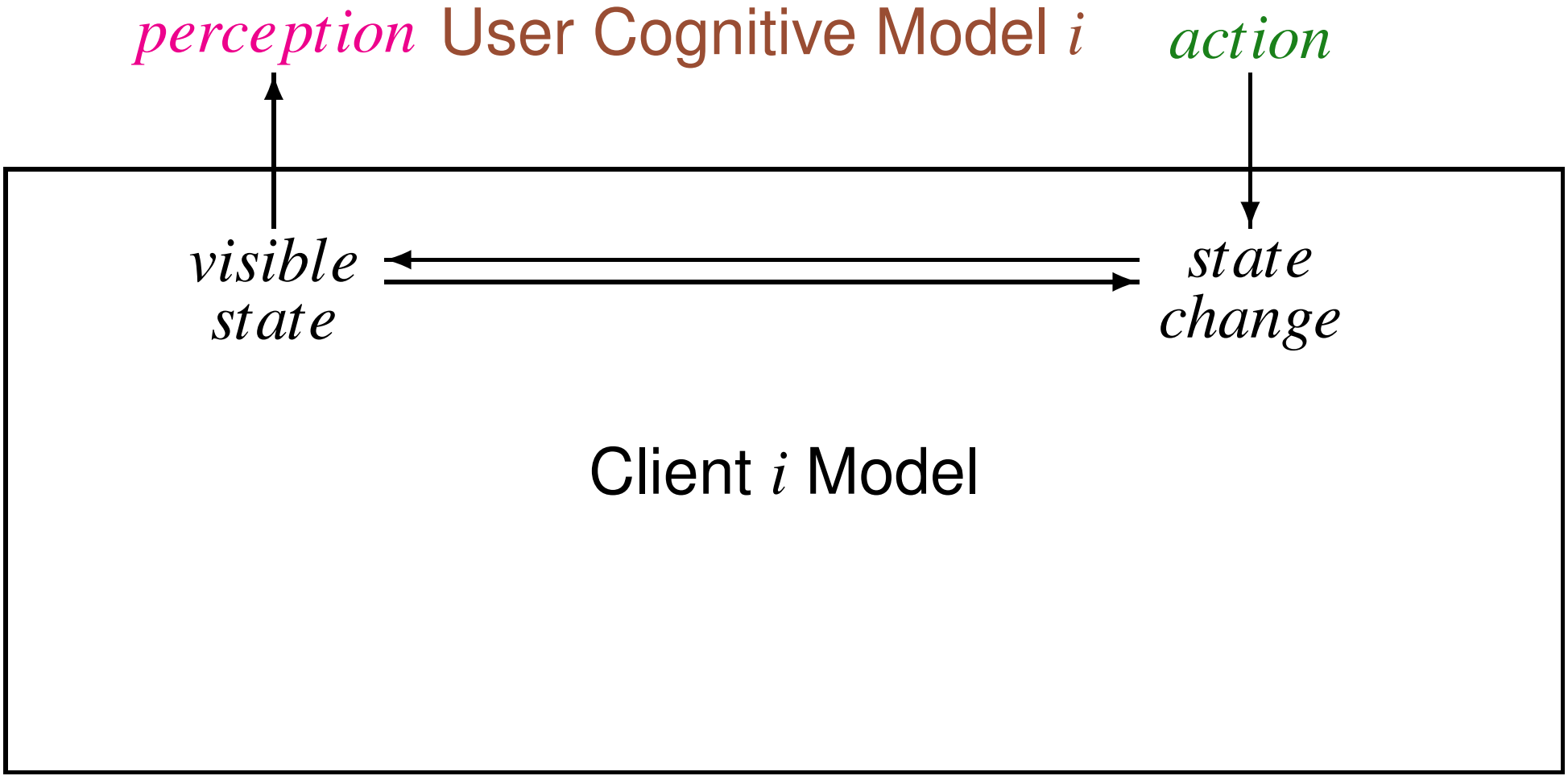
Client Model



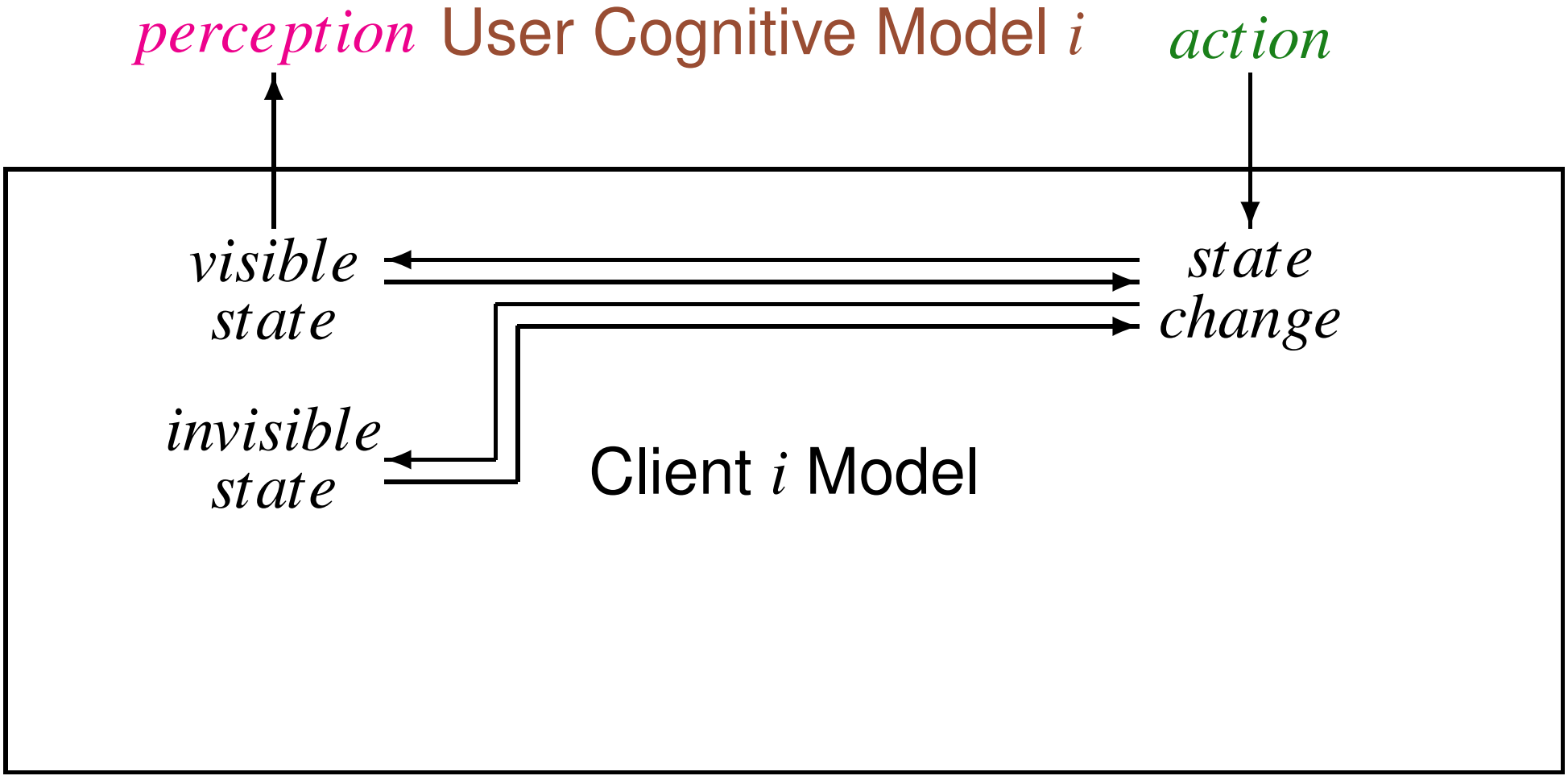
Client Model



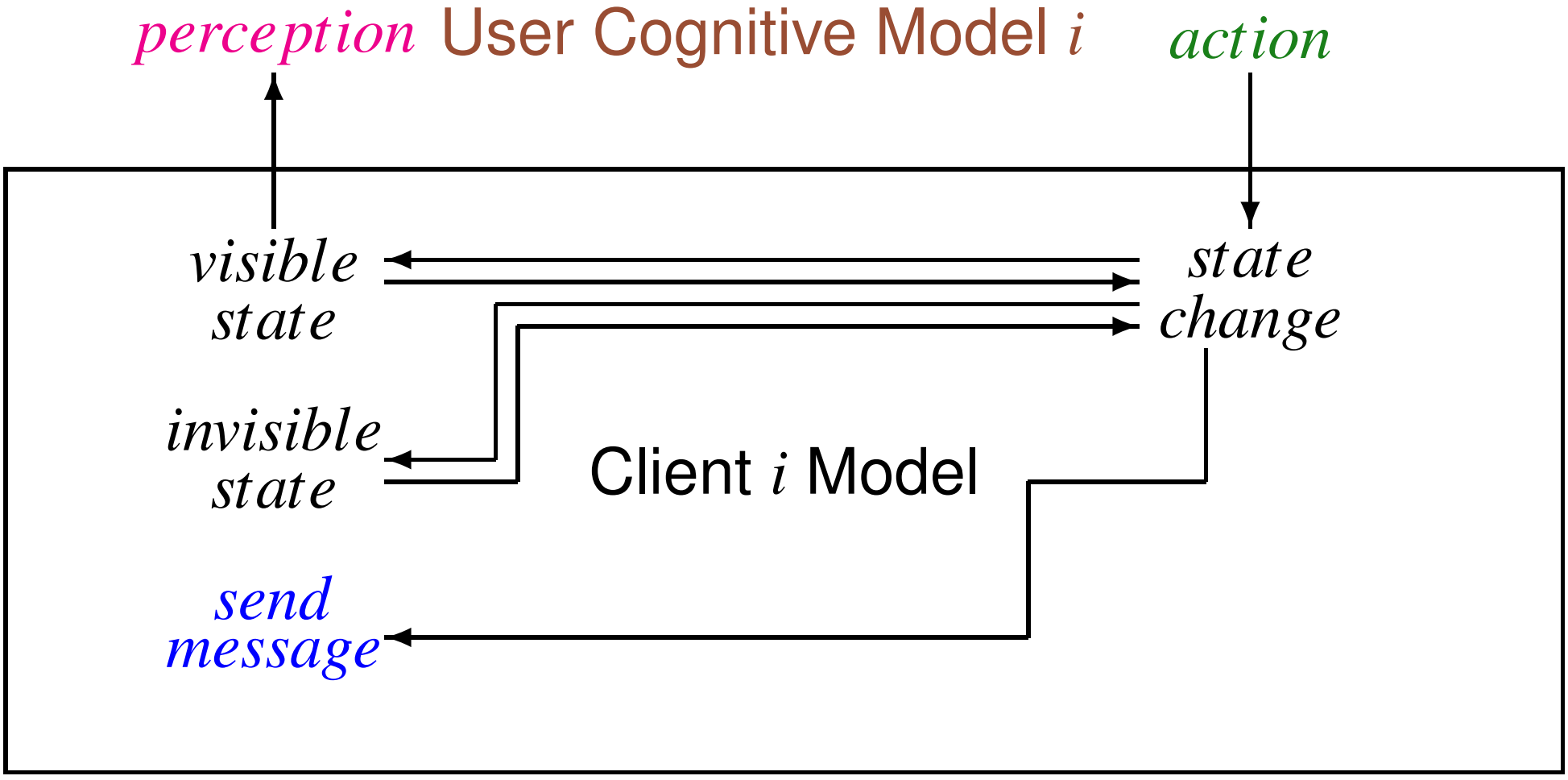
Client Model



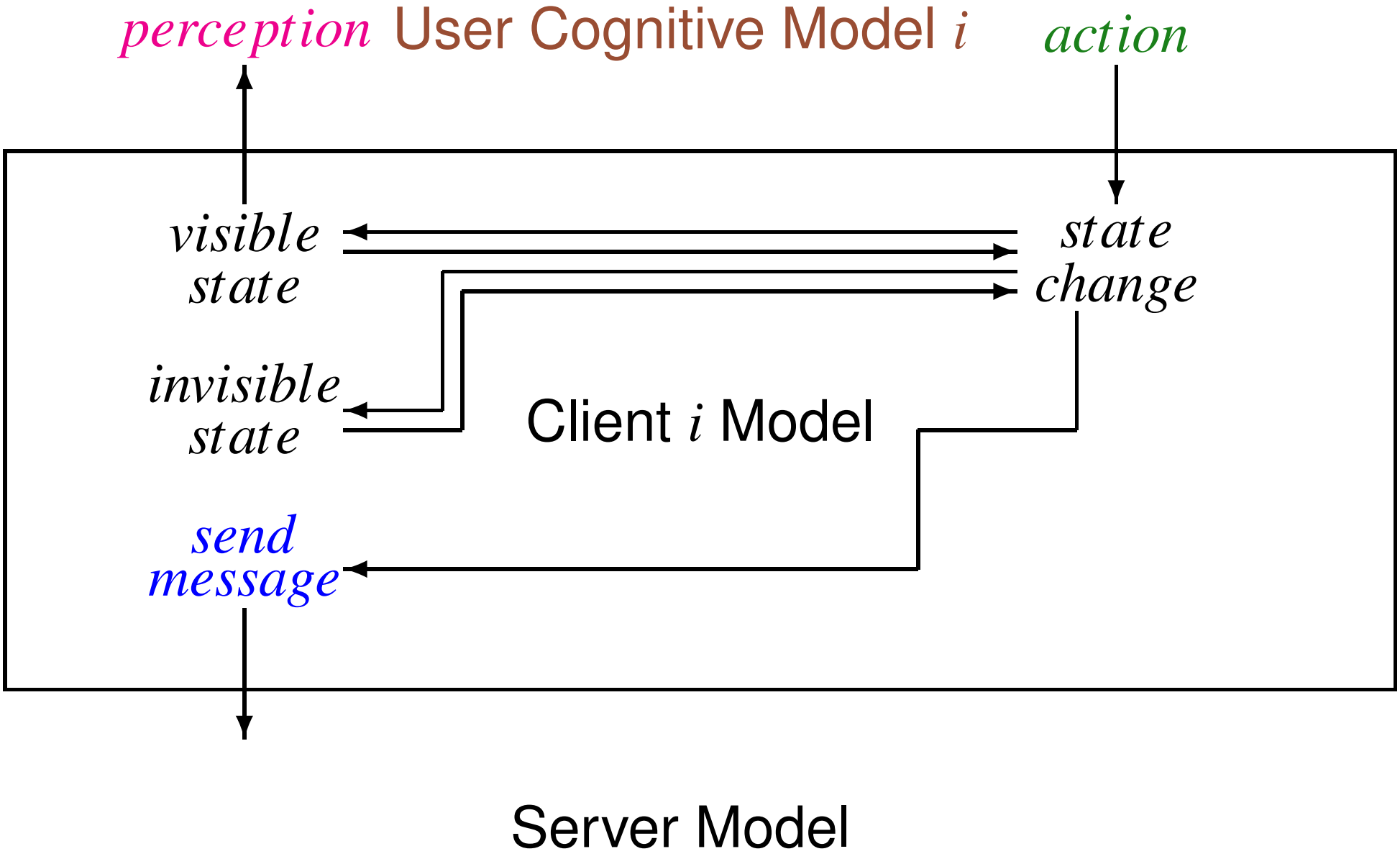
Client Model



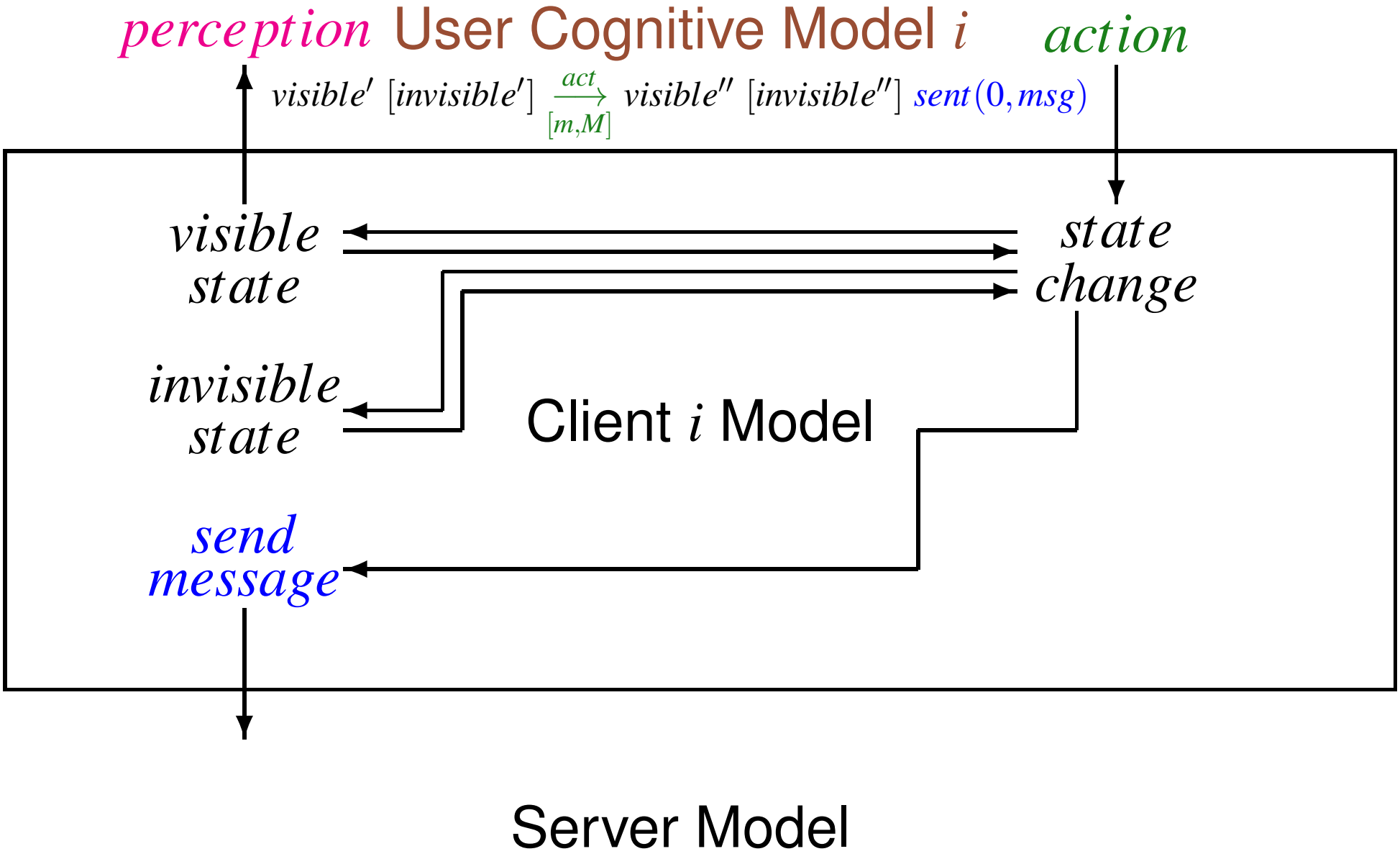
Client Model



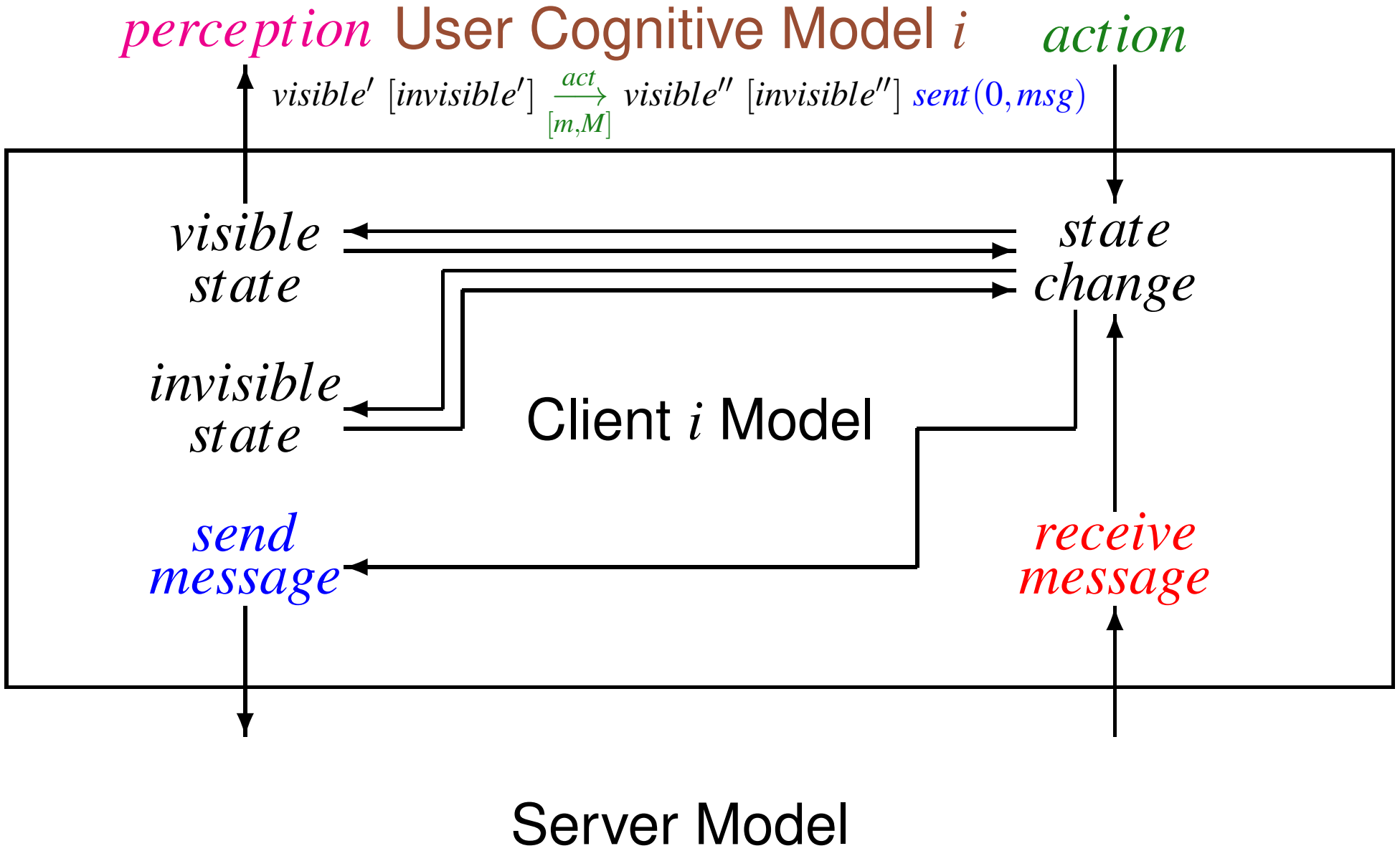
Client Model



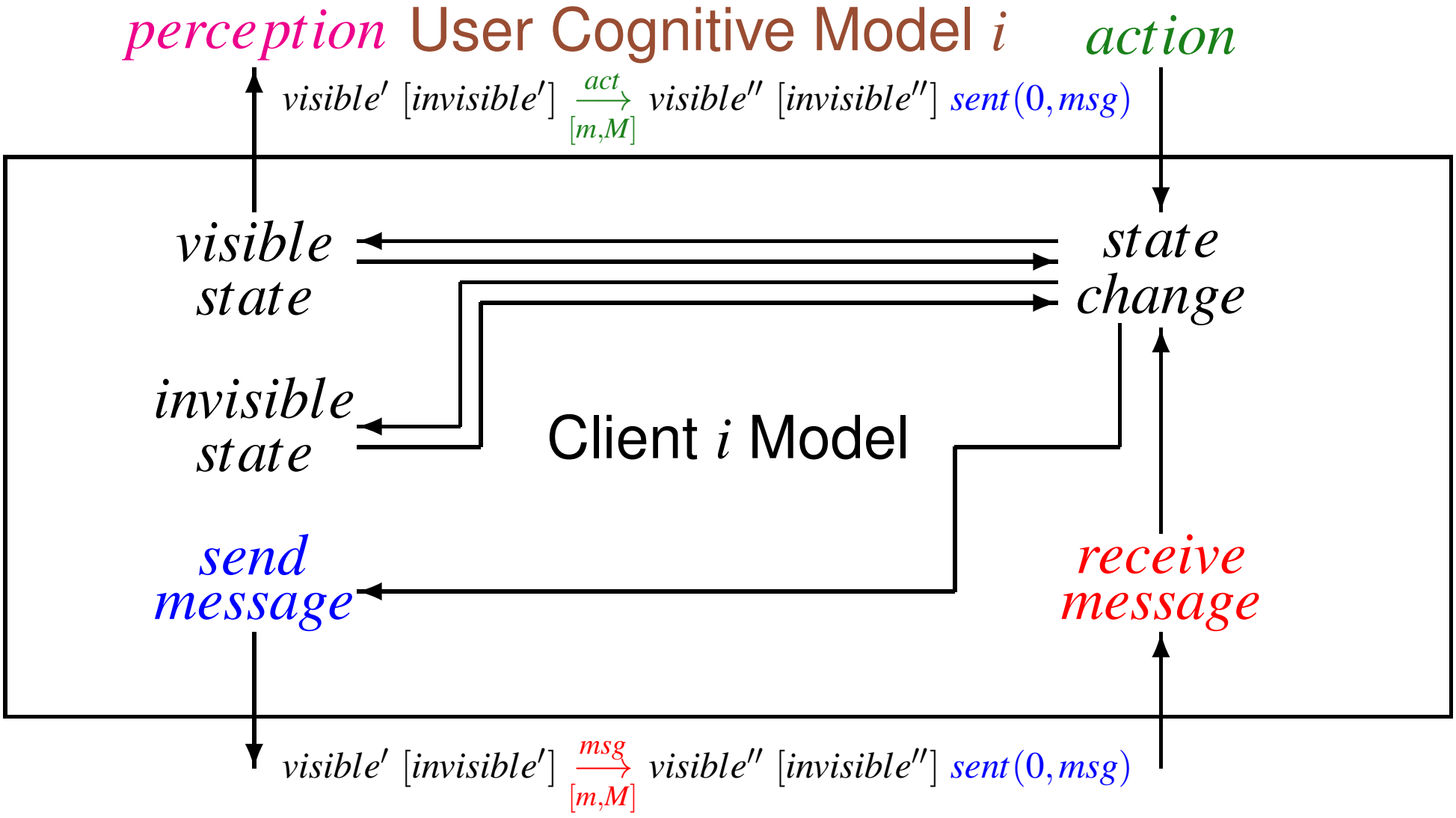
Client Model



Client Model



Client Model



Example: Client CLTS

$$emptyPage\ [] \xrightarrow[0]{refresh} waiting\ []\ sent(0, check_i)$$

$$waiting\ [] \xrightarrow[0]{available} available\ []$$

$$waiting\ [] \xrightarrow[0]{unavailable} unavailable\ []$$

$$available\ [] \xrightarrow[0]{enrol} enrolled\ [labs]\ sent(0, register_i)$$

$$enrolled\ [labs] \xrightarrow[0]{proceed} enrolled\ [loadingLabs]\ sent(0, checkLabs_i)$$

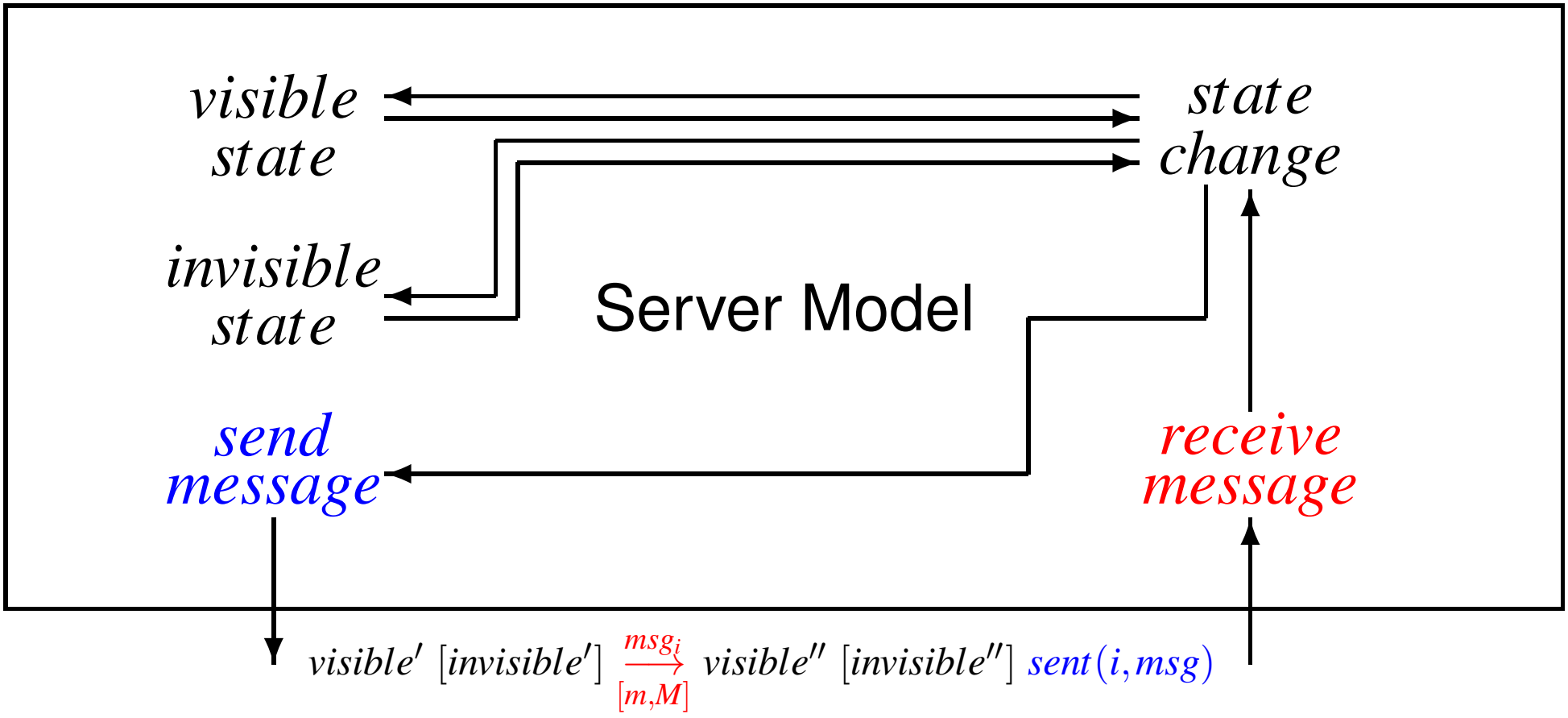
$$enrolled\ [loadingLabs] \xrightarrow[0]{labInfo} chooseLab\ []$$

$$enrolled\ [loadingLabs] \xrightarrow[0]{labFailed} enrolled\ [labs]$$

$$chooseLab\ [] \xrightarrow[0]{proceed} noLab\ []$$

$$chooseLab\ [] \xrightarrow[0]{registerLab} labRegistered\ []\ sent(0, labChosen_i)$$

Server Model



Example: Server CLTS

$$[available] \xrightarrow[[10,1000]]{check_i} [available]\ sent(i, available)$$

$$[unavailable] \xrightarrow[[10,1000]]{check_i} [unavailable]\ sent(i, unavailable)$$

$$[available] \xrightarrow[[10,1000]]{register_i} [unavailable, registered_i]$$

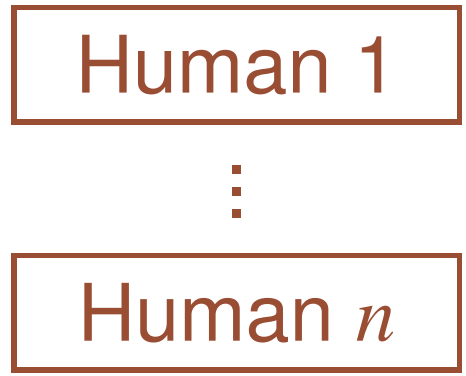
$$[unavailable] \xrightarrow[[10,1000]]{register_i} [unavailable]$$

$$[] \xrightarrow[[10,1000]]{checkLabs_i} []\ sent(i, labInfo)$$

$$[] \xrightarrow[[10,1000]]{checkLabs_i} []\ sent(i, labFailed)$$

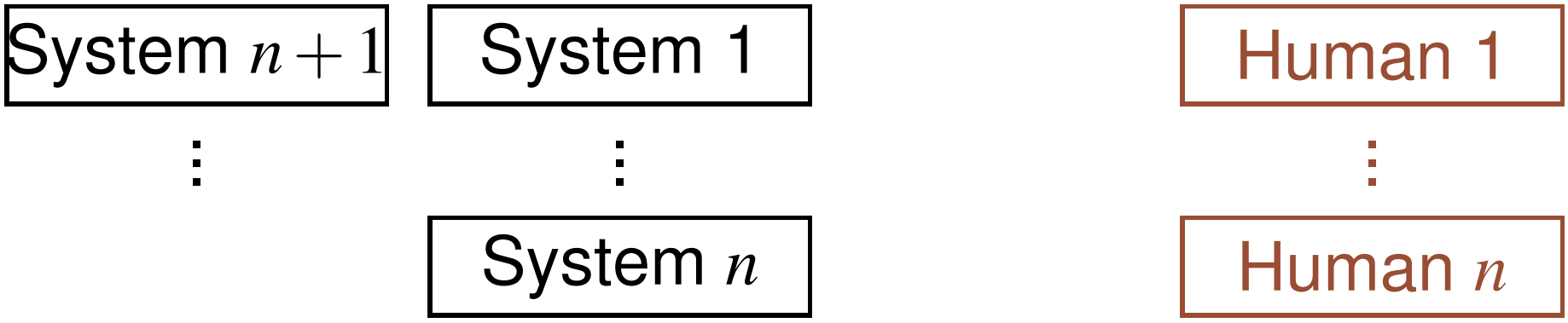
$$[] \xrightarrow[[10,1000]]{labChosen_i} [labRegistered_i]$$

Overall System Model (OSM)



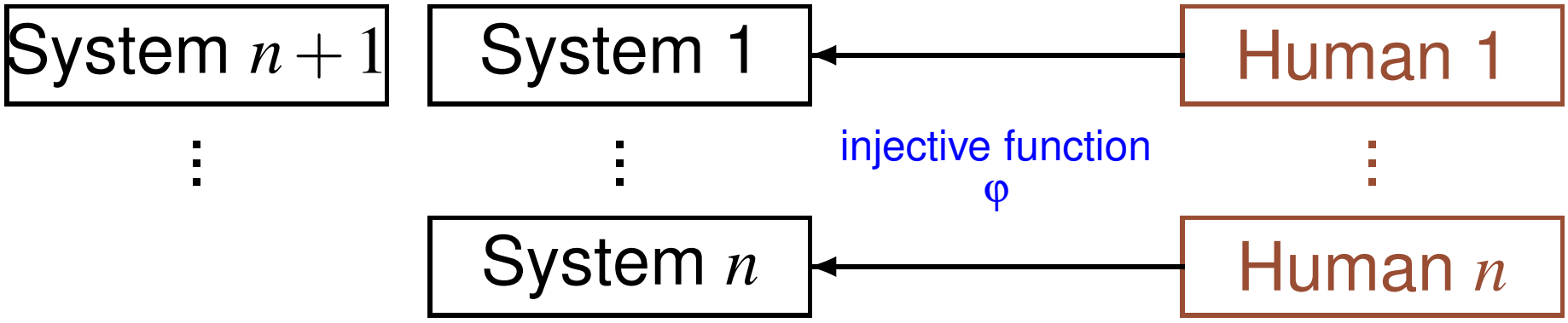
$$\{\mathcal{U}j\}_{j\in\mathbb{J}}$$

Overall System Model (OSM)



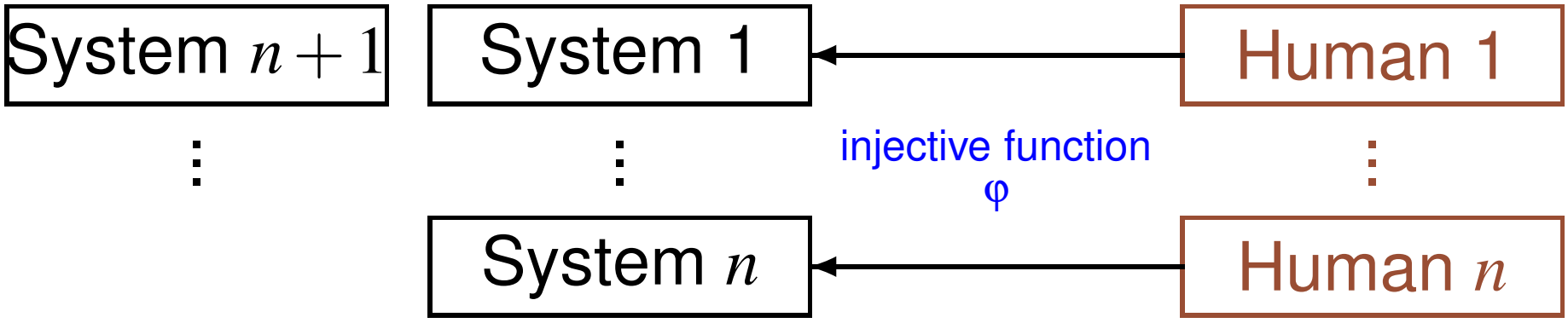
$\{\mathcal{S}_i\}_{i\in\mathbb{I}}$ $\{\mathcal{U}_j\}_{j\in\mathbb{J}}$

Overall System Model (OSM)



$\{\mathcal{S}_i\}_{i\in\mathbb{I}}$ $\{\mathcal{U}_j\}_{j\in\mathbb{J}}$

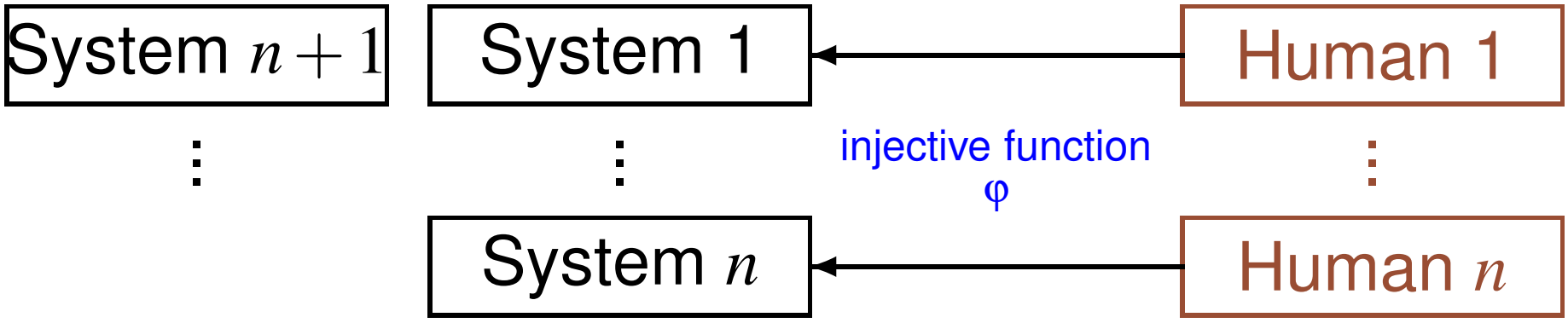
Overall System Model (OSM)



Network

$\{\mathcal{S}_i\}_{i\in\mathbb{I}}$ μ $\{\mathcal{U}_j\}_{j\in\mathbb{J}}$

Overall System Model (OSM)

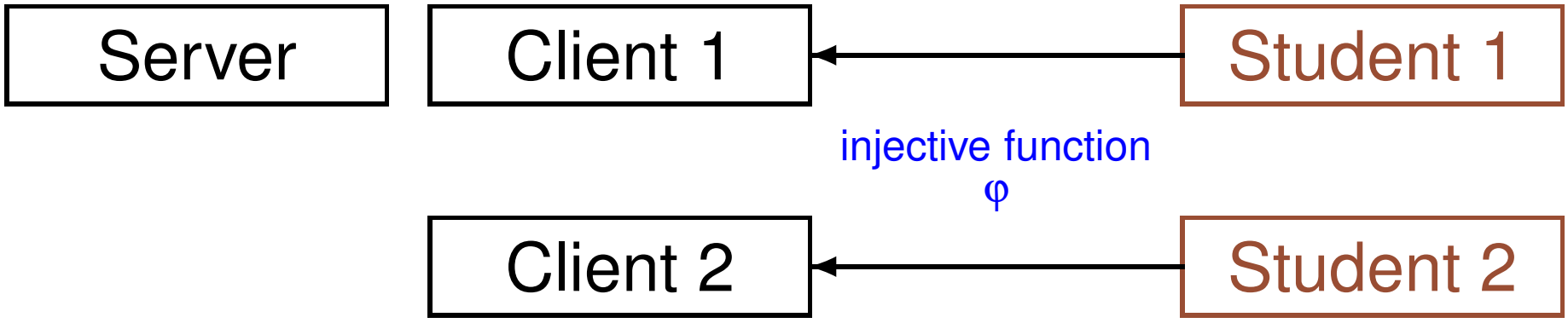


Network

$\{\mathcal{S}_i\}_{i\in\mathbb{I}}$ μ $\{\mathcal{U}j\}_{j\in\mathbb{J}}$

$$\mathcal{M} = \langle \{\mathcal{S}_i\}_{i\in\mathbb{I}}, \{\mathcal{U}j\}_{j\in\mathbb{J}}, \varphi, \mu \rangle$$

OSM Example



$\{\mathcal{S}_1, \mathcal{S}_2\}$ $\emptyset$ $\{\mathcal{U}_1, \mathcal{U}_2\}$

$$\mathcal{M} = \langle \{\mathcal{S}_1, \mathcal{S}_2\}, \{\mathcal{U}_1, \mathcal{U}_2\}, \varphi, \emptyset \rangle$$

Cognitive Properties

1. Only one student believes to have registered for the one place course;
2. A student cannot unintentionally skip the lab registration.

Formal Analysis of Cognitive Property 1

1. Only one student believes to have registered for the one place course.

Formal Analysis of Cognitive Property 1

1. Only one student believes to have registered for the one place course.

Search Condition: $(enrolled, T') \in STM' \wedge (enrolled, T'') \in STM''$

Formal Analysis of Cognitive Property 1

1. Only one student believes to have registered for the one place course.

Search Condition: $(enrolled, T') \in STM' \wedge (enrolled, T'') \in STM''$

The search should fail to validate Property 1

Formal Analysis of Cognitive Property 1

1. Only one student believes to have registered for the one place course.

Search Condition: $(enrolled, T') \in STM' \wedge (enrolled, T'') \in STM''$

The search should fail to validate Property 1

But it doesn't $\Longrightarrow$ Property 1 does not hold

Property 1 Violation: Server Side

1. Only one student believes to have registered for the one place course.

Search Condition: $(enrolled, T') \in STM' \wedge (enrolled, T'') \in STM''$

$$[available] \xrightarrow[[10,1000]]{check_i} [available]\ sent(i, available)$$

$$[unavailable] \xrightarrow[[10,1000]]{check_i} [unavailable]\ sent(i, unavailable)$$

$$[available] \xrightarrow[[10,1000]]{register_i} [unavailable, registered_i]$$

$$[unavailable] \xrightarrow[[10,1000]]{register_i} [unavailable]$$

$$[] \xrightarrow[[10,1000]]{checkLabs_i} []\ sent(i, labInfo)$$

$$[] \xrightarrow[[10,1000]]{checkLabs_i} []\ sent(i, labFailed)$$

$$[] \xrightarrow[[10,1000]]{labChosen_i} [labRegistered_i]$$

Property 1 Violation: Server Side

1. Only one student believes to have registered for the one place course.

Search Condition: $(enrolled, T') \in STM' \wedge (enrolled, T'') \in STM''$

$$[available] \xrightarrow[[10,1000]]{check_i} [available]\ sent(i, available)$$

$$[unavailable] \xrightarrow[[10,1000]]{check_i} [unavailable]\ sent(i, unavailable)$$

$$[available] \xrightarrow[[10,1000]]{register_i} [unavailable, registered_i]$$

$$[unavailable] \xrightarrow[[10,1000]]{register_i} [unavailable]$$ (no message is sent to Client i)

$$[] \xrightarrow[[10,1000]]{checkLabs_i} []\ sent(i, labInfo)$$

$$[] \xrightarrow[[10,1000]]{checkLabs_i} []\ sent(i, labFailed)$$

$$[] \xrightarrow[[10,1000]]{labChosen_i} [labRegistered_i]$$

Property 1 Violation: Client Side

$$emptyPage\ [] \xrightarrow[0]{refresh} waiting\ []\ sent(0, check_i)$$

$$waiting\ [] \xrightarrow[0]{available} available\ []$$

$$waiting\ [] \xrightarrow[0]{unavailable} unavailable\ []$$

$$available\ [] \xrightarrow[0]{enrol} enrolled\ [labs]\ sent(0, register_i)$$

$$enrolled\ [labs] \xrightarrow[0]{proceed} enrolled\ [loadingLabs]\ sent(0, checkLabs_i)$$

$$enrolled\ [loadingLabs] \xrightarrow[0]{labInfo} chooseLab\ []$$

$$enrolled\ [loadingLabs] \xrightarrow[0]{labFailed} enrolled\ [labs]$$

$$chooseLab\ [] \xrightarrow[0]{proceed} noLab\ []$$

$$chooseLab\ [] \xrightarrow[0]{registerLab} labRegistered\ []\ sent(0, labChosen_i)$$

Property 1 Violation: Client Side

$$emptyPage\ [] \xrightarrow[0]{refresh} waiting\ []\ sent(0, check_i)$$

$$waiting\ [] \xrightarrow[0]{available} available\ []$$

$$waiting\ [] \xrightarrow[0]{unavailable} unavailable\ []$$

$$available\ [] \xrightarrow[0]{enrol} enrolled\ [labs]\ sent(0, register_i)$$ (immediate feedback to the user)

$$enrolled\ [labs] \xrightarrow[0]{proceed} enrolled\ [loadingLabs]\ sent(0, checkLabs_i)$$

$$enrolled\ [loadingLabs] \xrightarrow[0]{labInfo} chooseLab\ []$$

$$enrolled\ [loadingLabs] \xrightarrow[0]{labFailed} enrolled\ [labs]$$

$$chooseLab\ [] \xrightarrow[0]{proceed} noLab\ []$$

$$chooseLab\ [] \xrightarrow[0]{registerLab} labRegistered\ []\ sent(0, labChosen_i)$$

Formal Analysis of Cognitive Property 2

2. A student cannot unintentionally skip the lab registration.

Formal Analysis of Cognitive Property 2

2. A student cannot unintentionally skip the lab registration.

Search Condition: there is a Client which may reach
a visible state that contains $noLab$
when starting with $goal(registerLab) \in STM$

Formal Analysis of Cognitive Property 2

2. A student cannot unintentionally skip the lab registration.

Search Condition: there is a Client which may reach
a visible state that contains $noLab$
when starting with $goal(registerLab) \in STM$

The search should fail to validate Property 2

Formal Analysis of Cognitive Property 2

2. A student cannot unintentionally skip the lab registration.

Search Condition: there is a Client which may reach
a visible state that contains $noLab$
when starting with $goal(registerLab) \in STM$

The search should fail to validate Property 2

(The search should instead succeed when starting with $goal(noLab) \in STM$)

Formal Analysis of Cognitive Property 2

2. A student cannot unintentionally skip the lab registration.

Search Condition: there is a Client which may reach
a visible state that contains $noLab$
when starting with $goal(registerLab) \in STM$

The search should fail to validate Property 2

(The search should instead succeed when starting with $goal(noLab) \in STM$)

But it doesn't $\Longrightarrow$ Property 2 does not hold

Property 2 Violation: Client Side

$$emptyPage\ [] \xrightarrow[0]{refresh} waiting\ []\ sent(0, check_i)$$

$$waiting\ [] \xrightarrow[0]{available} available\ []$$

$$waiting\ [] \xrightarrow[0]{unavailable} unavailable\ []$$

$$available\ [] \xrightarrow[0]{enrol} enrolled\ [labs]\ sent(0, register_i)$$

$$enrolled\ [labs] \xrightarrow[0]{proceed} enrolled\ [loadingLabs]\ sent(0, checkLabs_i)$$

$$enrolled\ [loadingLabs] \xrightarrow[0]{labInfo} chooseLab\ []$$

$$enrolled\ [loadingLabs] \xrightarrow[0]{labFailed} enrolled\ [labs]$$

$$chooseLab\ [] \xrightarrow[0]{proceed} noLab\ []$$

Property 2 Violation: Client Side

$$emptyPage\ [] \xrightarrow[0]{refresh} waiting\ []\ sent(0, check_i)$$

$$waiting\ [] \xrightarrow[0]{available} available\ []$$

$$waiting\ [] \xrightarrow[0]{unavailable} unavailable\ []$$

$$available\ [] \xrightarrow[0]{enrol} enrolled\ [labs]\ sent(0, register_i)$$

$$enrolled\ [labs] \xrightarrow[0]{proceed} enrolled\ [loadingLabs]\ sent(0, checkLabs_i)$$

$$enrolled\ [loadingLabs] \xrightarrow[0]{labInfo} chooseLab\ []$$

$$enrolled\ [loadingLabs] \xrightarrow[0]{labFailed} enrolled\ [labs]$$

$$chooseLab\ [] \xrightarrow[0]{proceed} noLab\ []$$

Property 2 Violation: Client Side

$$emptyPage\ [] \xrightarrow[0]{refresh} waiting\ []\ sent(0, check_i)$$

$$waiting\ [] \xrightarrow[0]{available} available\ []$$

$$waiting\ [] \xrightarrow[0]{unavailable} unavailable\ []$$

$$available\ [] \xrightarrow[0]{enrol} enrolled\ [labs]\ sent(0, register_i)$$

$$enrolled\ [labs] \xrightarrow[0]{proceed} enrolled\ [loadingLabs]\ sent(0, checkLabs_i)$$

$$enrolled\ [loadingLabs] \xrightarrow[0]{labInfo} chooseLab\ []$$

$$enrolled\ [loadingLabs] \xrightarrow[0]{labFailed} enrolled\ [labs]$$

$$chooseLab\ [] \xrightarrow[0]{proceed} noLab\ []$$

Property 2 Violation: Client Side

$$emptyPage\ [] \xrightarrow[0]{refresh} waiting\ []\ sent(0, check_i)$$

$$waiting\ [] \xrightarrow[0]{available} available\ []$$

$$waiting\ [] \xrightarrow[0]{unavailable} unavailable\ []$$

$$available\ [] \xrightarrow[0]{enrol} enrolled\ [labs]\ sent(0, register_i)$$

$$enrolled\ [labs] \xrightarrow[0]{proceed} enrolled\ [loadingLabs]\ sent(0, checkLabs_i)$$

$$enrolled\ [loadingLabs] \xrightarrow[0]{labInfo} chooseLab\ []$$

$$enrolled\ [loadingLabs] \xrightarrow[0]{labFailed} enrolled\ [labs]$$

$$chooseLab\ [] \xrightarrow[0]{proceed} noLab\ []$$

the user
keeps clicking *proceed*
to register for a lab

Property 2 Violation: Client Side

$$emptyPage\ [] \xrightarrow[0]{refresh} waiting\ []\ sent(0, check_i)$$

$$waiting\ [] \xrightarrow[0]{available} available\ []$$

$$waiting\ [] \xrightarrow[0]{unavailable} unavailable\ []$$

$$available\ [] \xrightarrow[0]{enrol} enrolled\ [labs]\ sent(0, register_i)$$

$$enrolled\ [labs] \xrightarrow[0]{proceed} enrolled\ [loadingLabs]\ sent(0, checkLabs_i)$$

$$enrolled\ [loadingLabs] \xrightarrow[0]{labInfo} chooseLab\ []$$

$$enrolled\ [loadingLabs] \xrightarrow[0]{labFailed} enrolled\ [labs]$$

$$chooseLab\ [] \xrightarrow[0]{proceed} noLab\ []$$

the user keeps clicking *proceed* to register for a lab

BUT

skips the lab registration instead

Conclusion and Future Work

Conclusion

- Use the Maude search command to detect violation of Cognitive Properties

Conclusion and Future Work

Conclusion

- Use the Maude search command to detect violation of Cognitive Properties
- Responsibility with the system, not the human

Conclusion and Future Work

Conclusion

- Use the Maude search command to detect violation of Cognitive Properties
- Responsibility with the system, not the human
- They are system errors, NOT human error

Conclusion and Future Work

Conclusion

- Use the Maude search command to detect violation of Cognitive Properties
- Responsibility with the system, not the human
- They are system errors, NOT human error

Future Work

- we have statically assigned users to interfaces

Conclusion and Future Work

Conclusion

- Use the Maude search command to detect violation of Cognitive Properties
- Responsibility with the system, not the human
- They are system errors, NOT human error

Future Work

- we have statically assigned users to interfaces
- we are exploring ways to dynamically assign users to interfaces

Contents

Contents