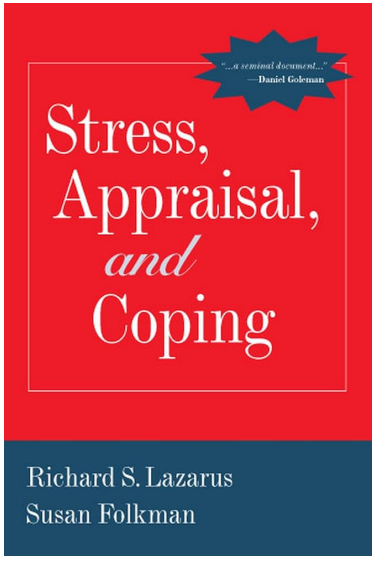
An Automata-Based Method to Formalize Psychological Theories : The Case Study of Lazarus and Folkman's Stress Theory

Gaspard Fougea, 2nd year PhD student at LMF under the direction of Alain Finkel and Stephane Le Roux
ENS Paris-Saclay



Stress, Appraisal and Coping(Lazarus & Folkman, 1984)

Outline

1. Why formal models for psychology?
2. Why finite automata?
3. Finite automata and communicating automata
4. Transactional theory of stress (Lazarus & Folkman, 1984)
5. Modeling the transactional theory
6. Mathematical transformations for theory-building
7. Conclusion

1. Why formal models for psychology?

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"We argue that **formal theories** *provide this much needed set of tools, equipping researchers with tools for thinking, evaluating explanation, enhancing* **measurement**, *informing* **theory development**, *and promoting the* **collaborative construction of psychological theories**."
Robinaugh et al, 2021

2. Why finite automata?

Why finite automata?

What to expect from a type of formalism?

1. Openness to all psychological theories, both cognitive and behavioral,
2. Modularity (easy to modify, compose, and refine),
3. Having a formal dynamic,
4. Formal composition and refinement,
5. Capability to handle large systems,
6. Possibility of step-by-step simulation,
7. Formal verification of properties (psychological model checking) with the use of automatic tools,
8. Formal (and automatic) comparison of models, with automatic determination of compatibility between theories.

Why finite automata?

What is verification?

- Identifying important properties with logical formulas or automata (specification)
- Mathematically verifying when these properties happen (bugs...)

- Finite automata can be automatically verified!

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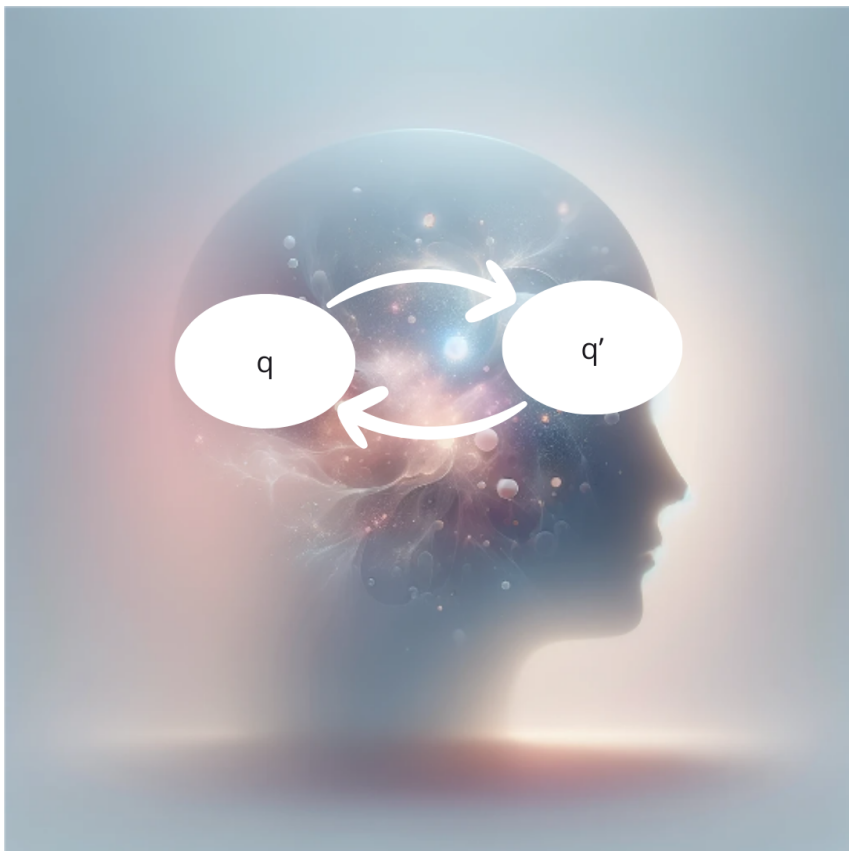
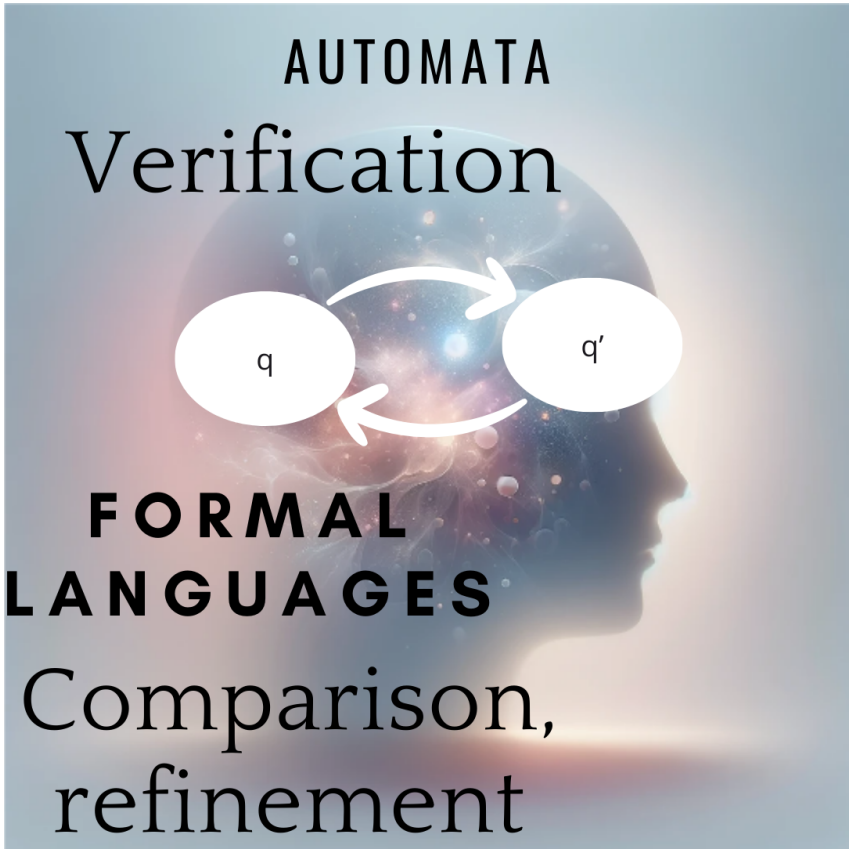
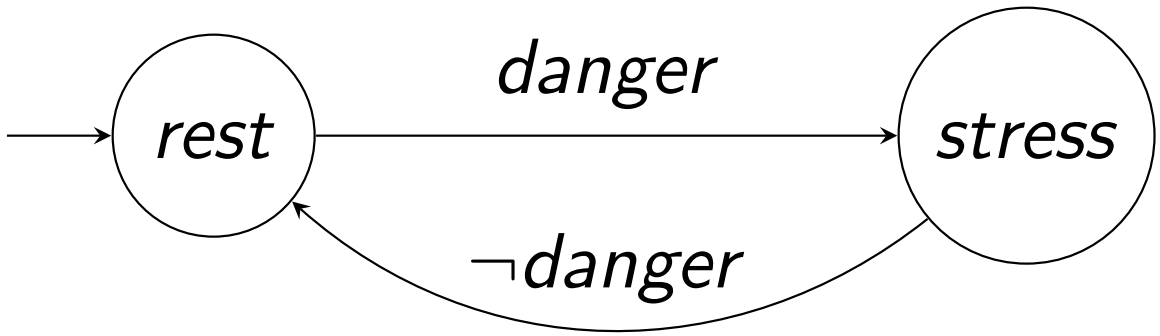


Why finite automata?

- Formal methods for psychology today : mostly statistics & probabilities.
- In psychological theories: we naturally identify states and transitions
- Theoretical CS: powerful tools to model these theories. Finite automata & extensions!



Why finite automata?



Basic understanding of stress

3. Finite automata and communicating automata

Finite automata and communicating automata

What is a finite automaton?

$\mathcal{A} = (\Sigma, Q, \delta, I)$

Finite automata and communicating automata

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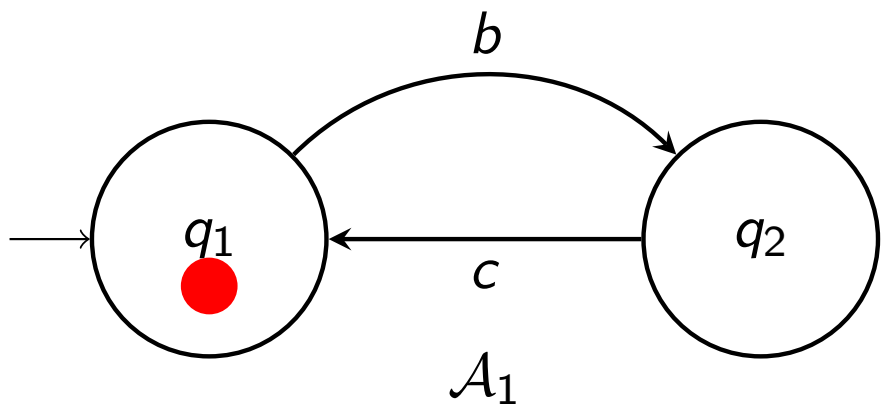
Example:



Finite automata and communicating automata

What is a finite automaton?

$\mathcal{A} = (\Sigma, Q, \delta, I)$

Σ an alphabet
Q set of states
$\delta \subseteq Q \times \Sigma \times Q$ set of transitions
$I \subseteq Q$ initial states

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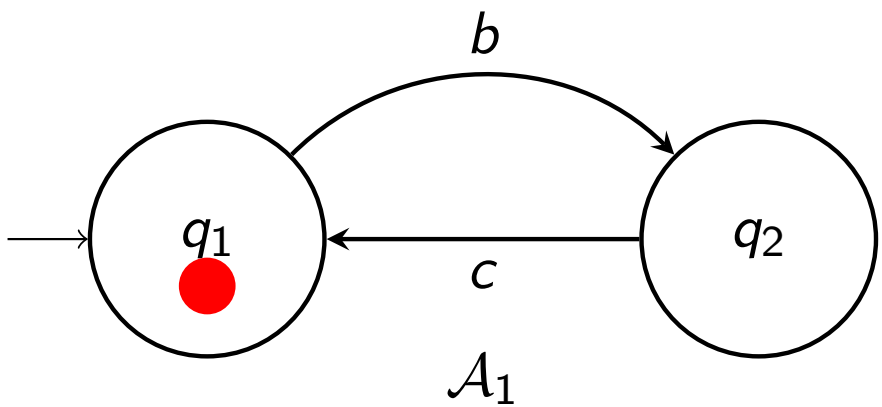

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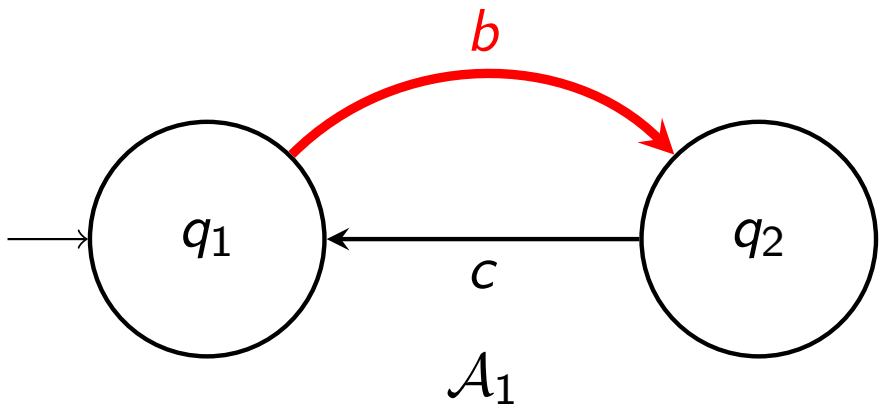

$\mathcal{A}_1$

Finite automata and communicating automata

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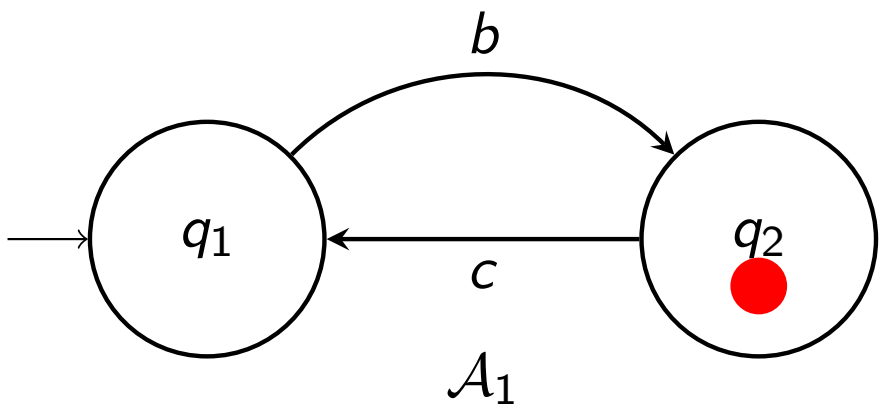
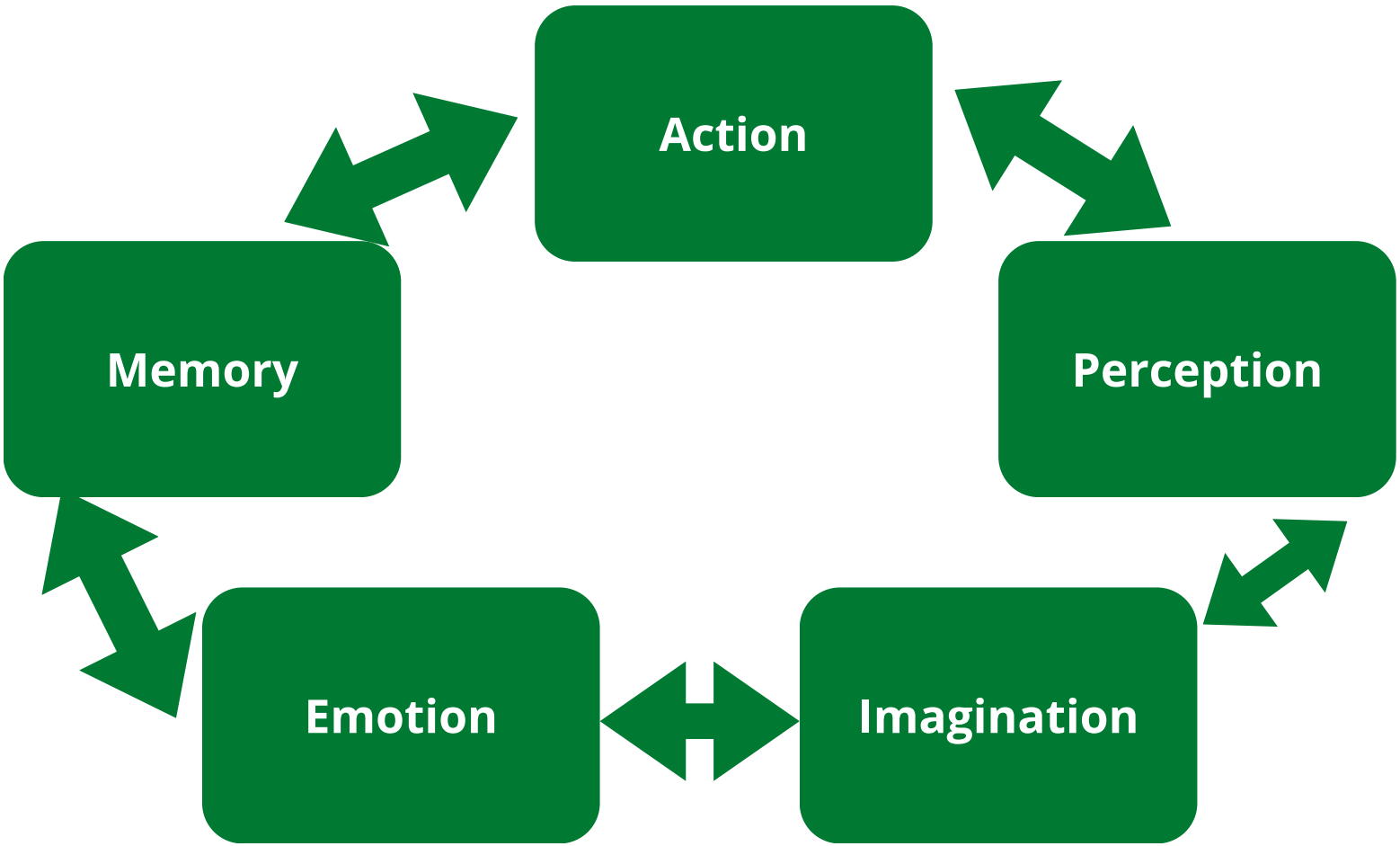


Finite automata and communicating automata

Communicating automata

N modules communicating $\rightarrow$ N automata.



Finite automata and communicating automata

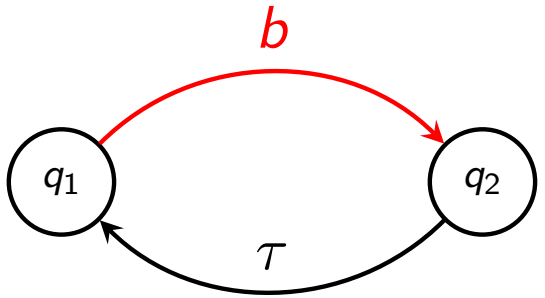
Communicating automata

Synchronisation via multiple "handshake" (Millner, 1989;Horn & Sangnier, 2020; ...)

Set of automata synchronise on letters.

Example:
System $(\mathcal{A}_1, \mathcal{A}_2, \mathcal{A}_3)$ synchronising on letter b

Rule: all automata with letter b must synchronise



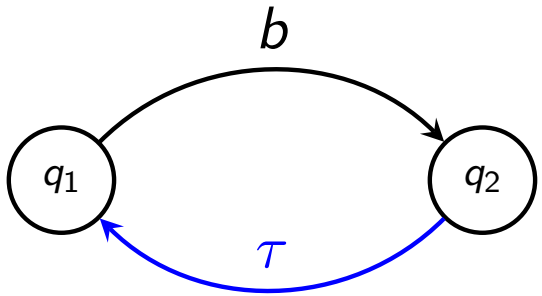
$\mathcal{A}_1$

$\mathcal{A}_2$ $\mathcal{A}_3$

Finite automata and communicating automata

Communicating automata: letter τ

- Meant to model imprecision "we don't know"
- τ-transitions don't synchronise with other automata



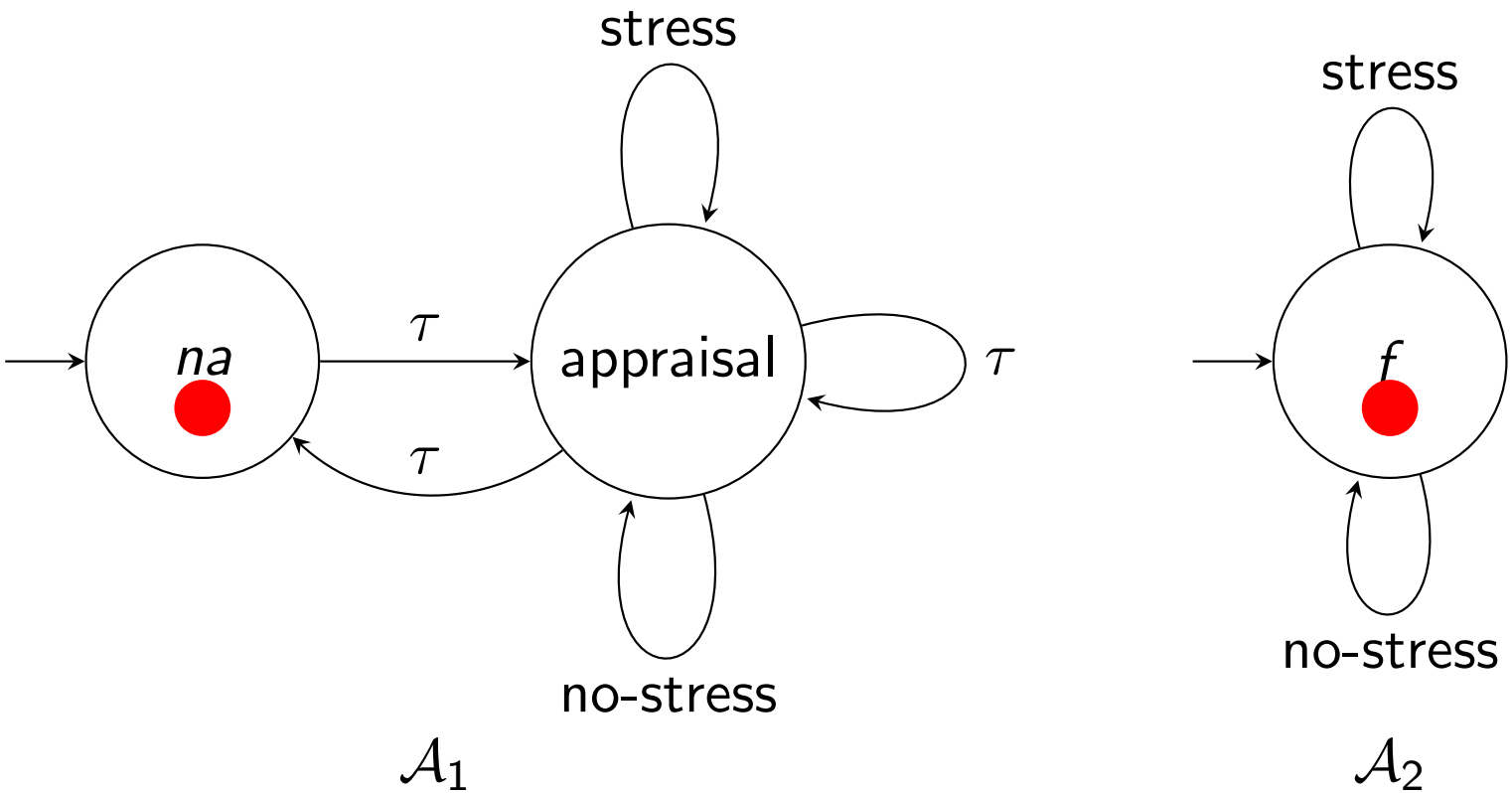
$\mathcal{A}_1$

τ-transition in $\mathcal{A}_1$ and
τ-transition in $\mathcal{A}_3$
happen independently!

$\mathcal{A}_2$ $\mathcal{A}_3$

Finite automata and communicating automata

Communicating automata: example



Finite automata and communicating automata

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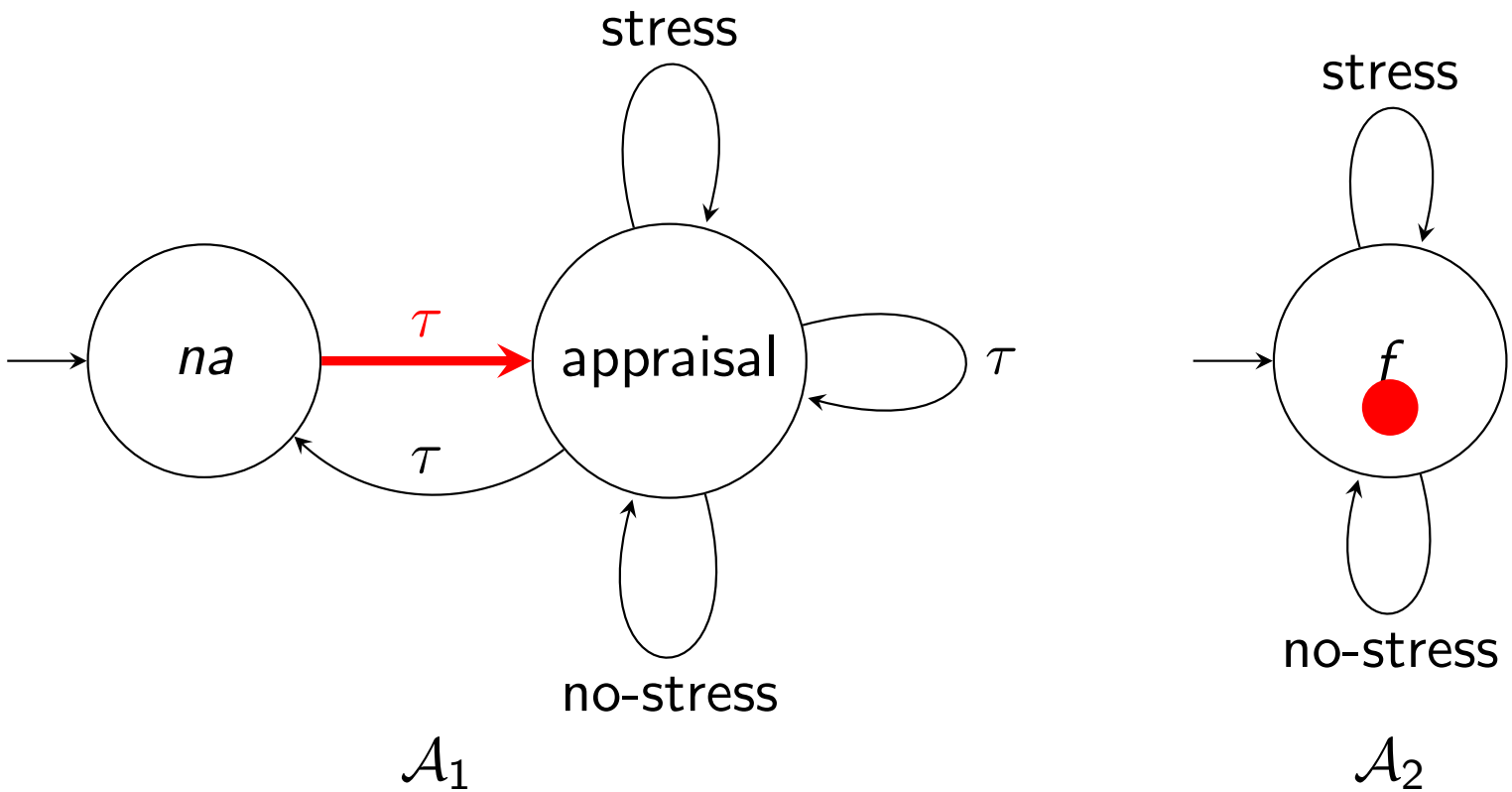

Finite automata and communicating automata

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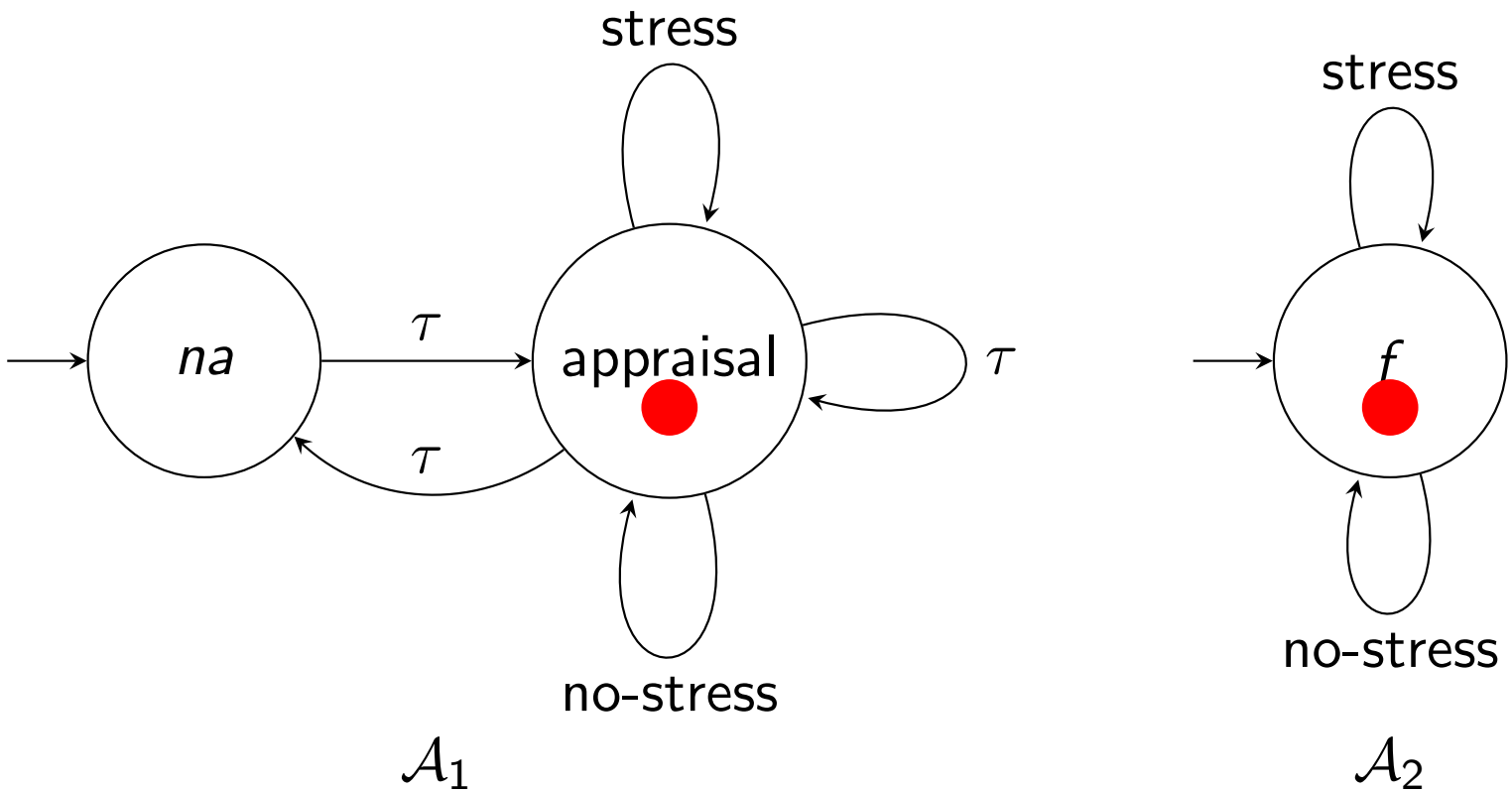
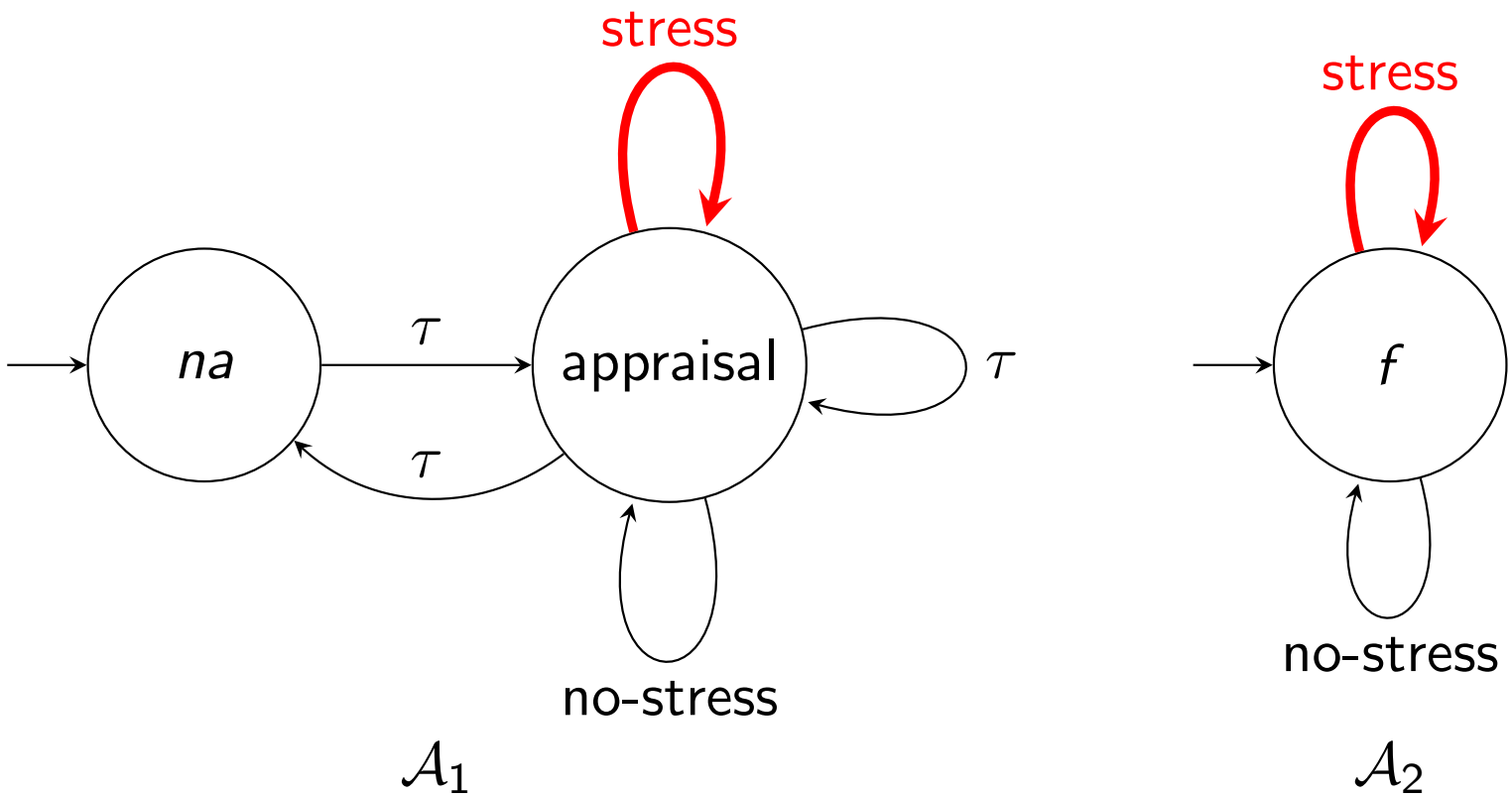


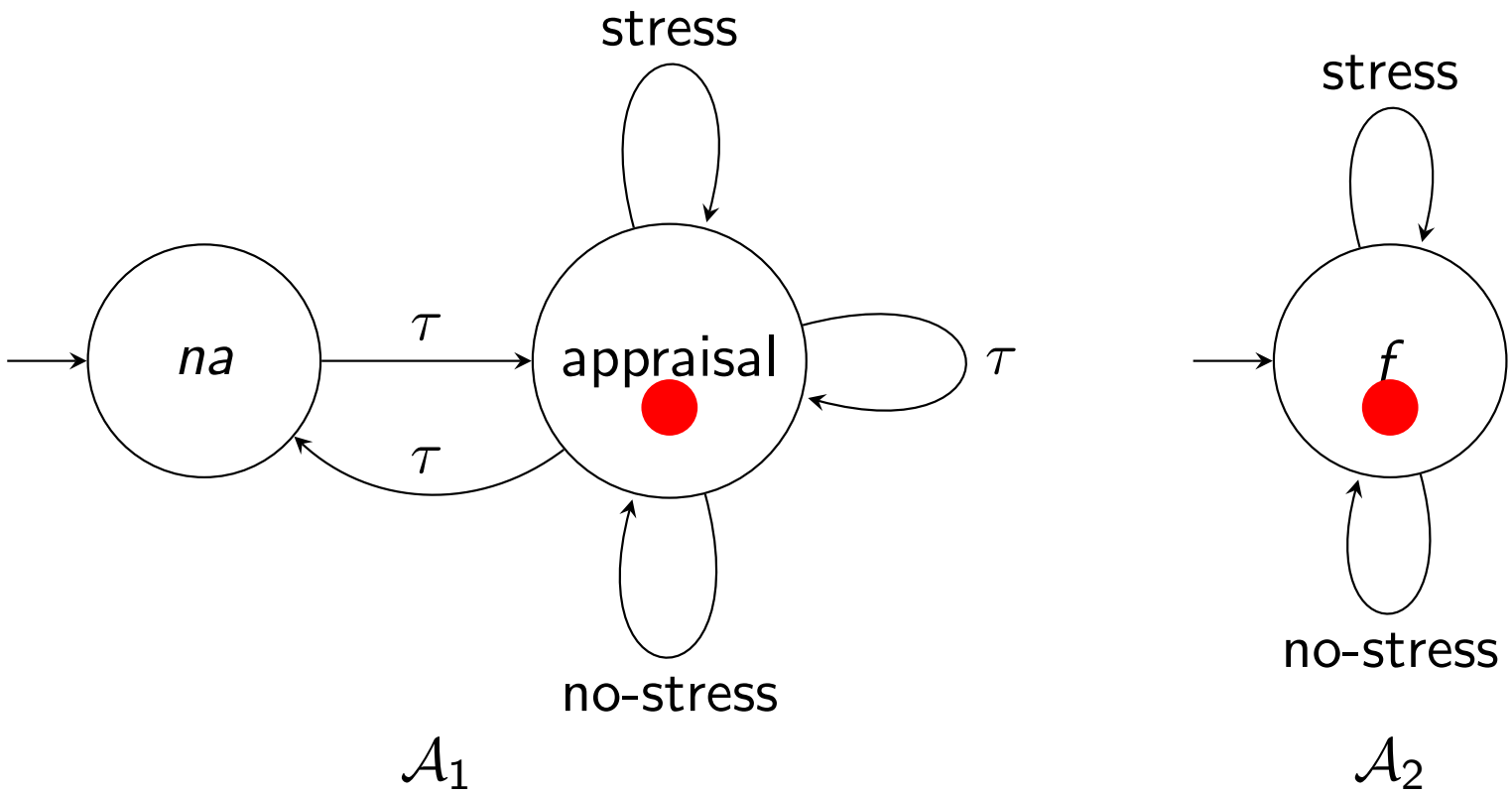
Finite automata and communicating automata

Communicating automata: example



Finite automata and communicating automata

Communicating automata: example



4. Lazarus and Folkman's theory of stress

Lazarus and Folkman's theory of stress

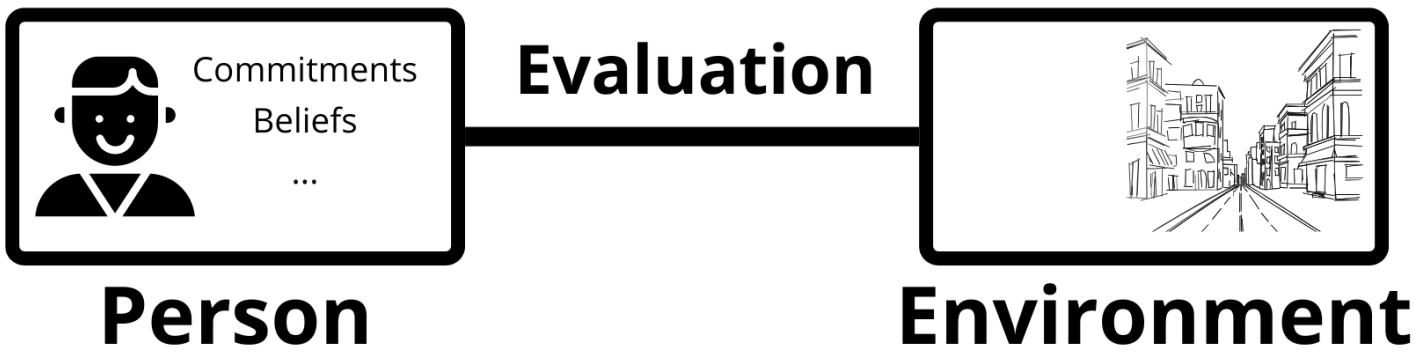
Person

Lazarus and Folkman's theory of stress

Person

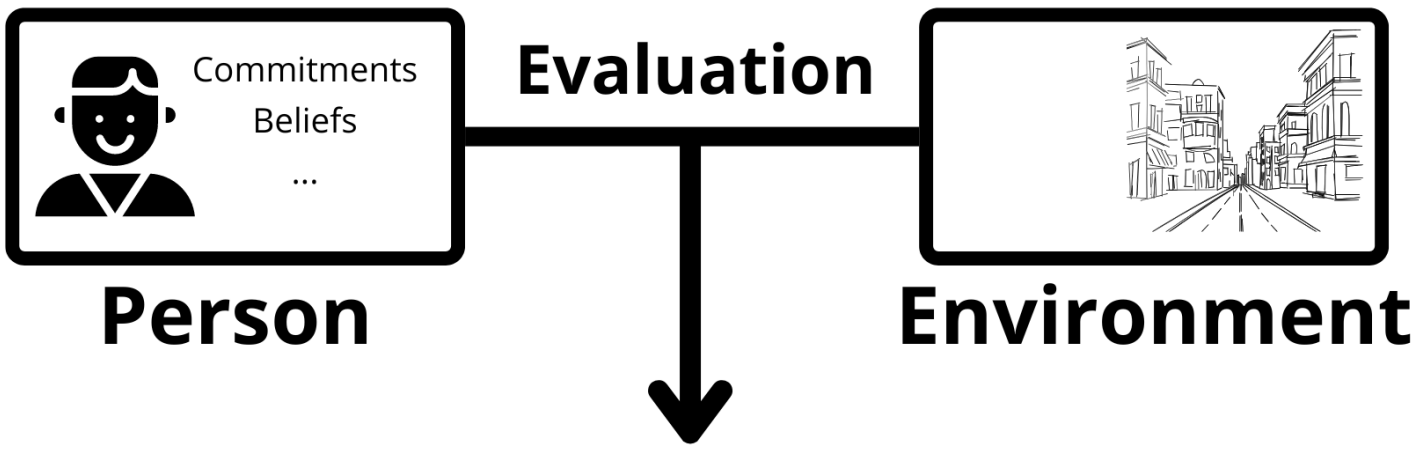
Environment

Lazarus and Folkman's theory of stress



Lazarus and Folkman's theory of stress

Appraisal= Evaluation



1. **Primary Appraisal:** endangering my well-being
2. **Secondary Appraisal:** taxing/exceeding my resources

Lazarus and Folkman's theory of stress

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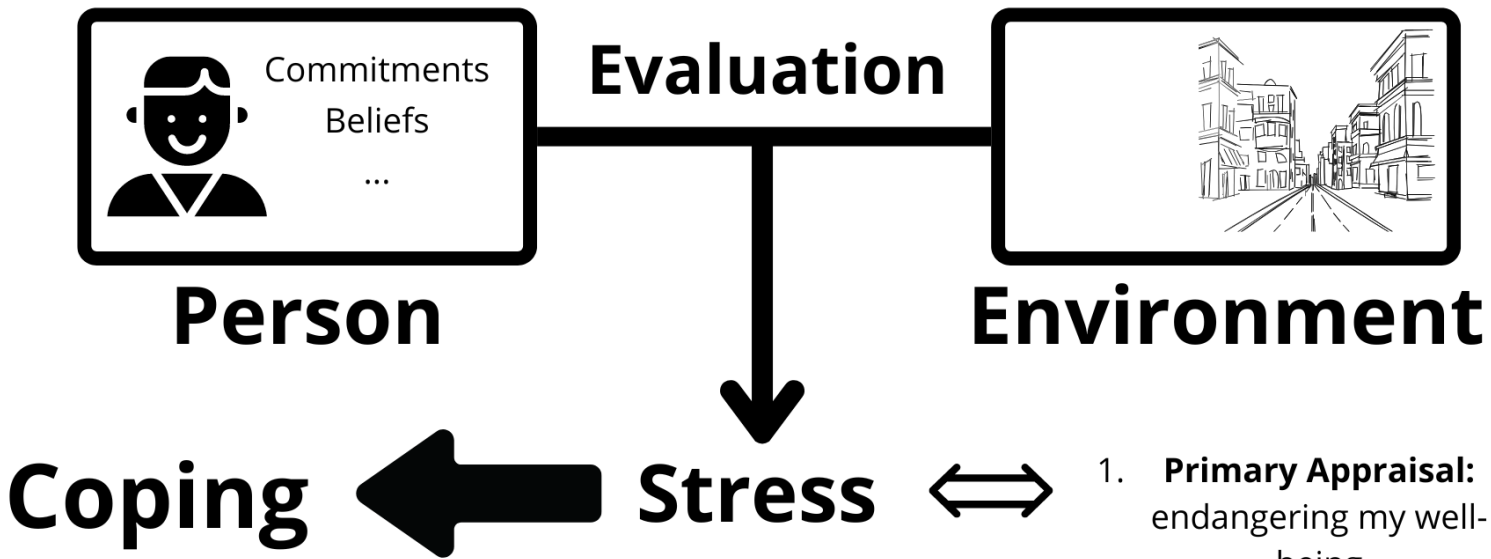

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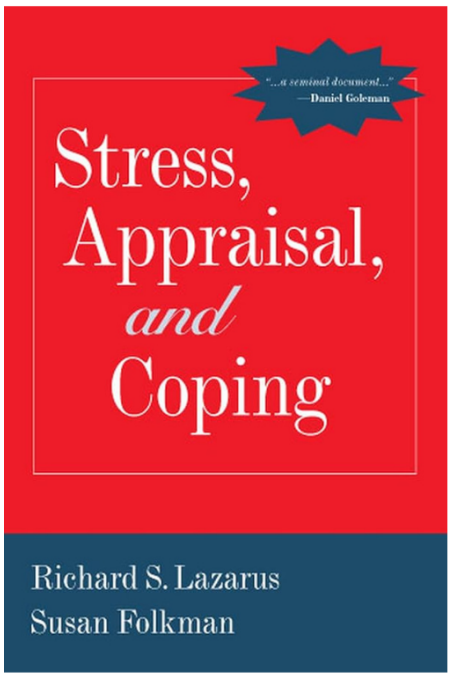
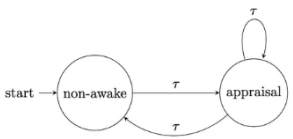
5. Modeling the transactional theory

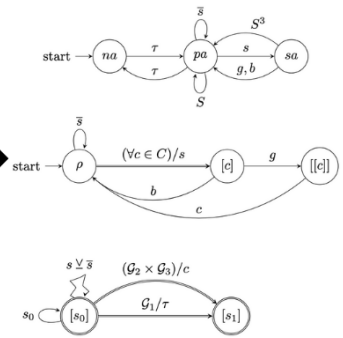
Modeling the transactional theory



Extracting key concepts, one at a time



Refining

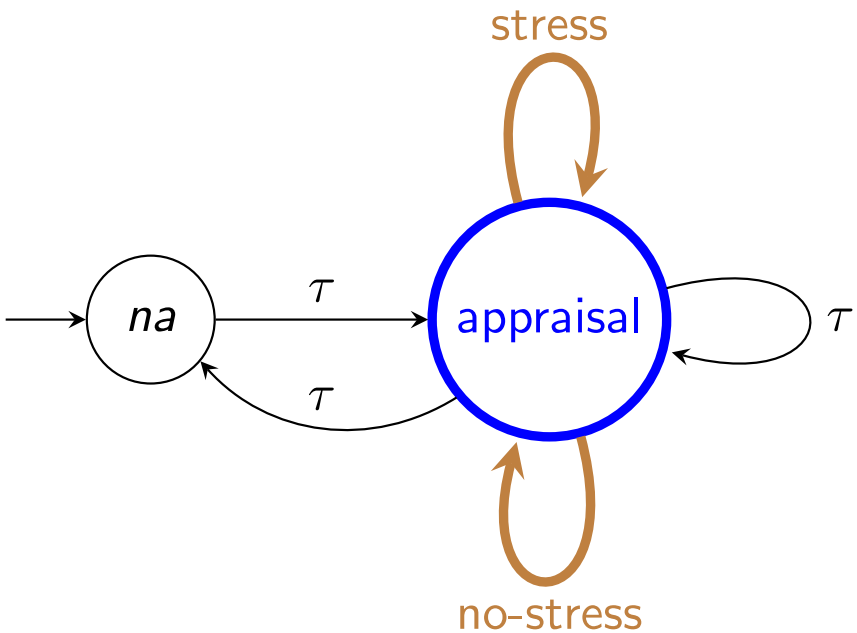


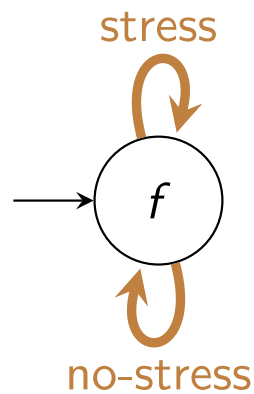
Verbal theory **Formal model**

Modeling the transactional theory

Modeling appraisal : System $\mathcal{S}_1$

"Cognitive appraisal is an evaluative process that determines why and to what extent a particular transaction or series of transactions between the person and the environment is stressful." (Lazarus & Folkman, 1984)





$\mathcal{A}_1$: **Cognitive Appraisal**

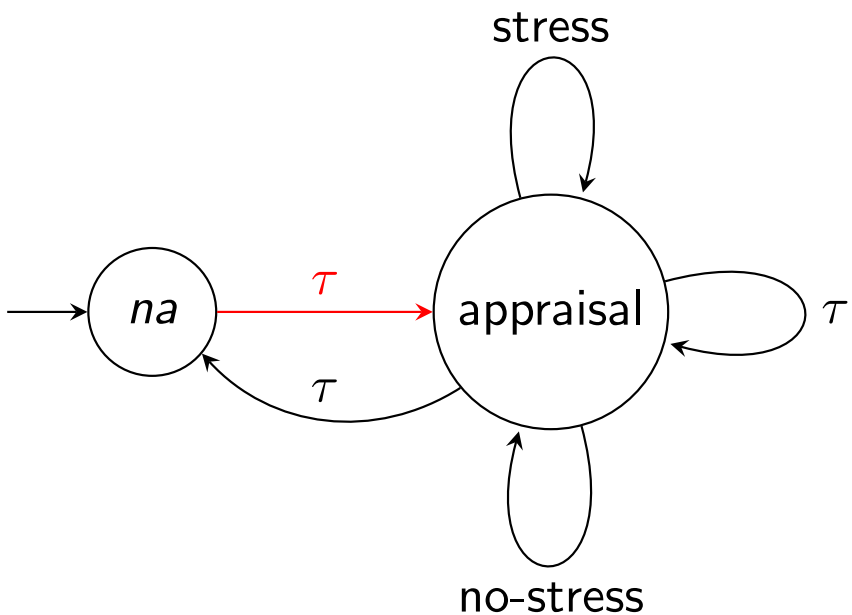
$\mathcal{A}_2$: **Evaluation of stress**

Modeling the transactional theory

Modeling appraisal : System $\mathcal{S}_1$

A person who wakes up, appraises the person-environment relationship as stressful, appraises again this relationship as non-stressful, then goes back to sleep:

$(non-awake, f) \xrightarrow{\tau} (appraisal, f) \xrightarrow{stress} (appraisal, f) \xrightarrow{no-stress} (appraisal, f) \xrightarrow{\tau} (non-awake, f)$



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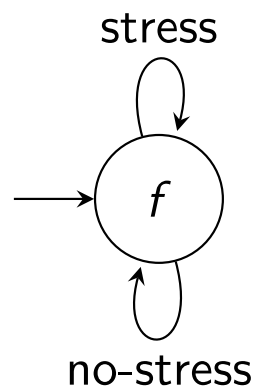

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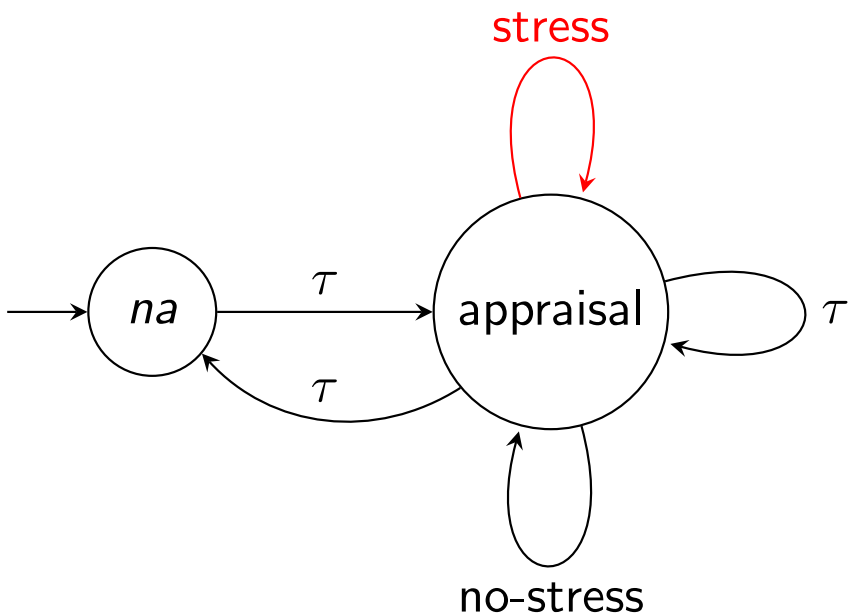

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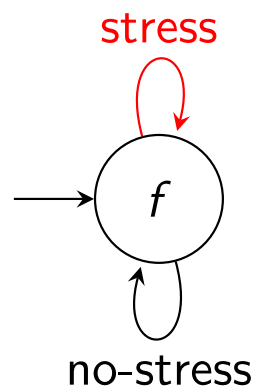

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Modeling the transactional theory

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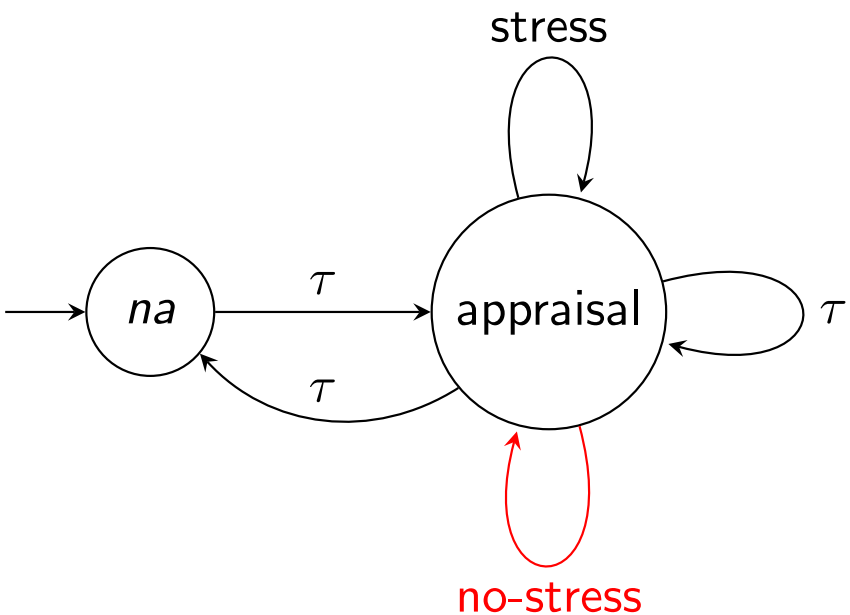
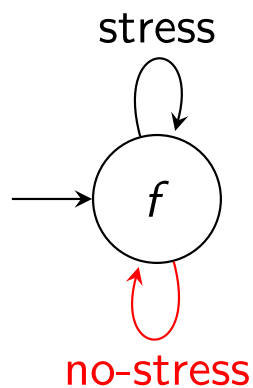


$\mathcal{A}_1$: **Cognitive Appraisal**



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Modeling the transactional theory

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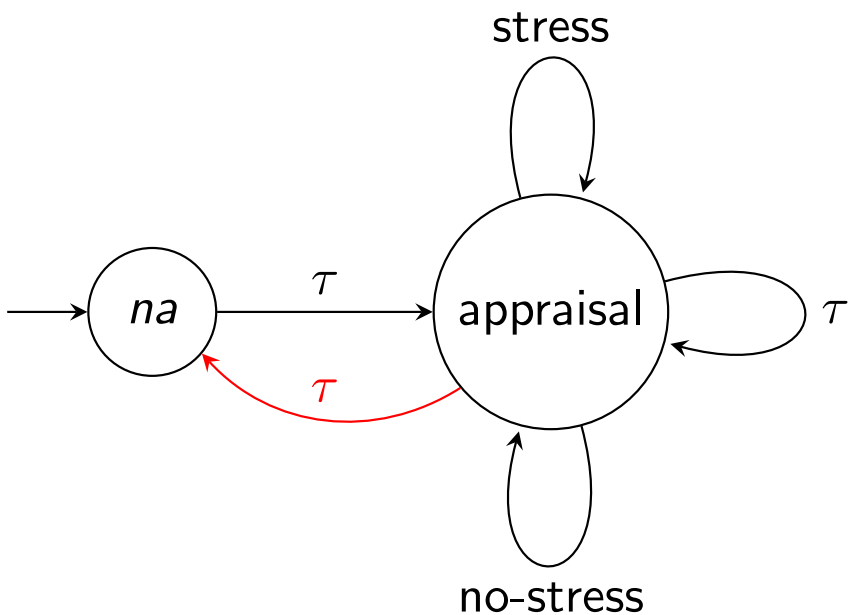

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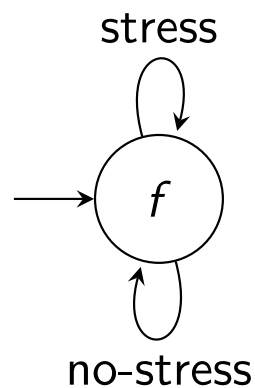
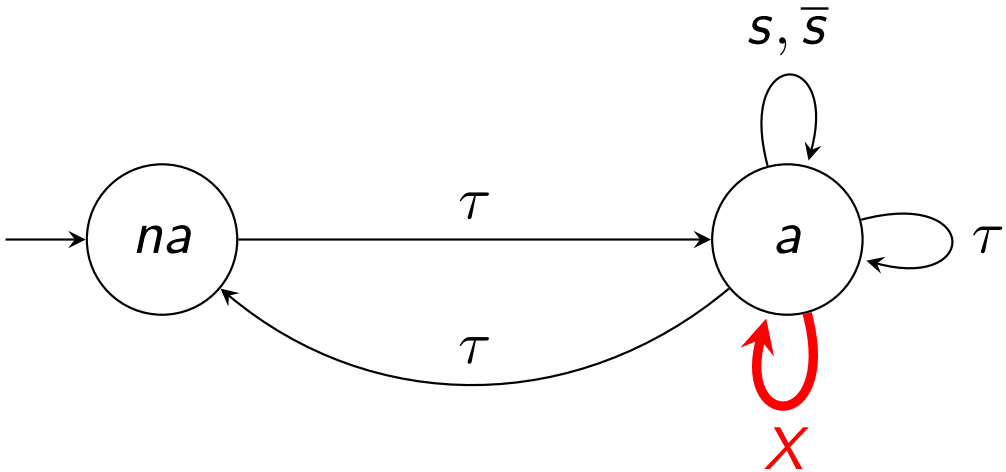


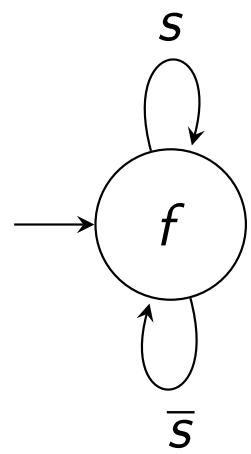
$\mathcal{A}_2$: **Evaluation of stress**

Modeling the transactional theory

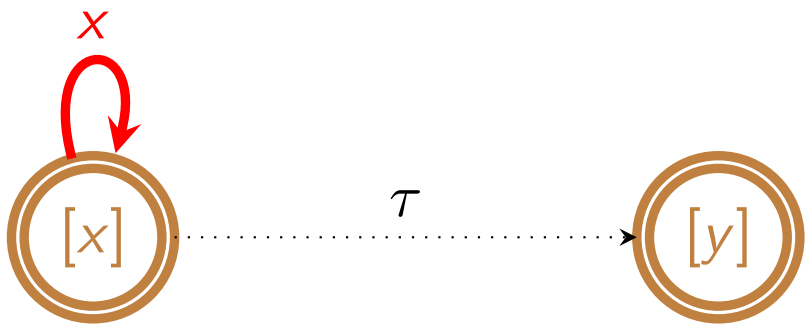
Adding the environment: Refining $\mathcal{S}_1$ into $\mathcal{S}_2$



$\mathcal{A}_1$ **Appraisal**



$\mathcal{A}_2$ **Evaluation of stress**



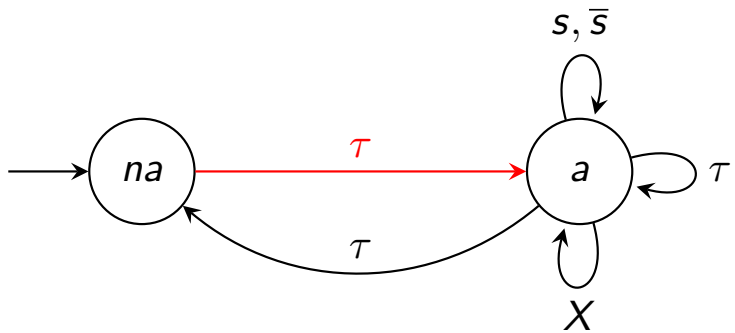
$\mathcal{A}_3$ **Environment**

Modeling the transactional theory

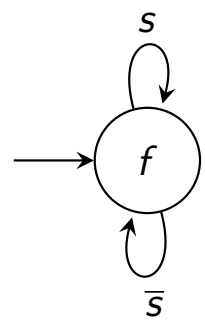
Adding the environment: Refining $\mathcal{S}_1$ into $\mathcal{S}_2$

A person who wakes up, perceives its environment, appraises the person-environment relationship as stressful, the environment changes by itself, the person perceives it, and appraises the new person-environment relationship as non-stressful.

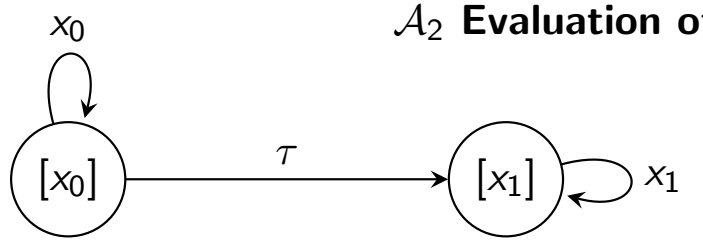
$(na, f, [x_0]) \xrightarrow{\tau} (a, f, [x_0]) \xrightarrow{x_0} (a, f, [x_0]) \xrightarrow{s} (a, f, [x_0]) \xrightarrow{\tau}$
$(a, f, [x_1]) \xrightarrow{x_1} (a, f, [x_1]) \xrightarrow{\overline{s}} (a, f, [x_1])$



$\mathcal{A}_1$ **Appraisal**



$\mathcal{A}_2$ **Evaluation of stress**



$\mathcal{A}_3$ **Environment**

Modeling the transactional theory

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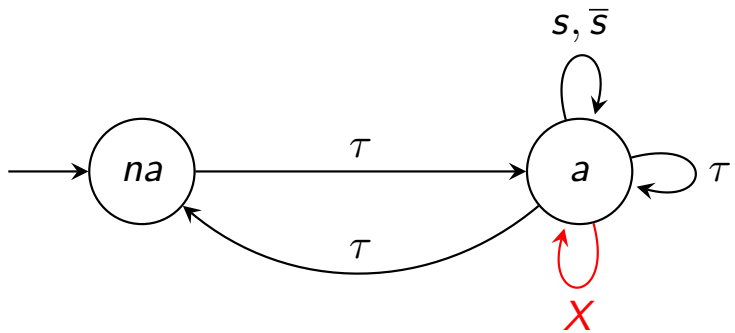
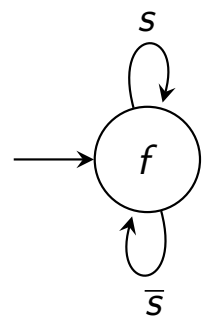
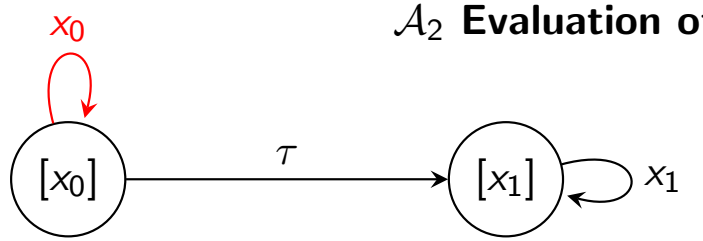


$\mathcal{A}_1$ **Appraisal**



$\mathcal{A}_2$ **Evaluation of stress**



$\mathcal{A}_3$ **Environment**

Modeling the transactional theory

Adding the environment: Refining $\mathcal{S}_1$ into $\mathcal{S}_2$

A person who wakes up, perceives its environment, appraises the person-environment relationship as stressful, the environment changes by itself, the person perceives it, and appraises the new person-environment relationship as non-stressful.

$(na, f, [x_0]) \xrightarrow{\tau} (a, f, [x_0]) \xrightarrow{x_0} (a, f, [x_0]) \xrightarrow{s} (a, f, [x_0]) \xrightarrow{\tau}$
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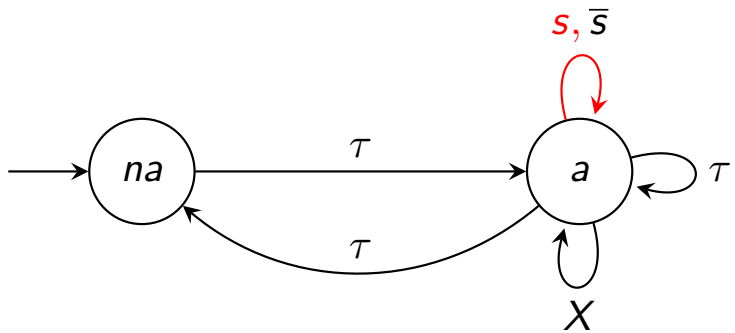
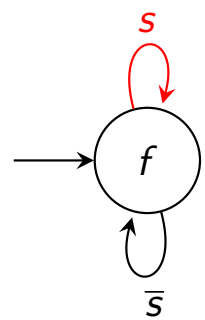
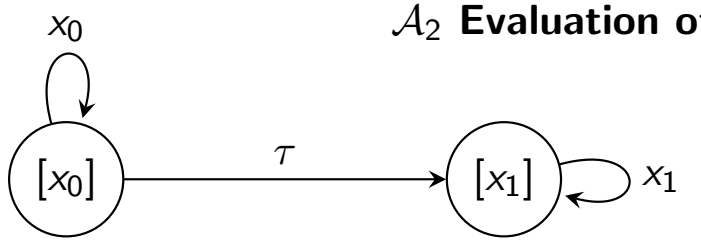


$\mathcal{A}_1$ **Appraisal**



$\mathcal{A}_2$ **Evaluation of stress**



$\mathcal{A}_3$ **Environment**

Modeling the transactional theory

Adding the environment: Refining $\mathcal{S}_1$ into $\mathcal{S}_2$

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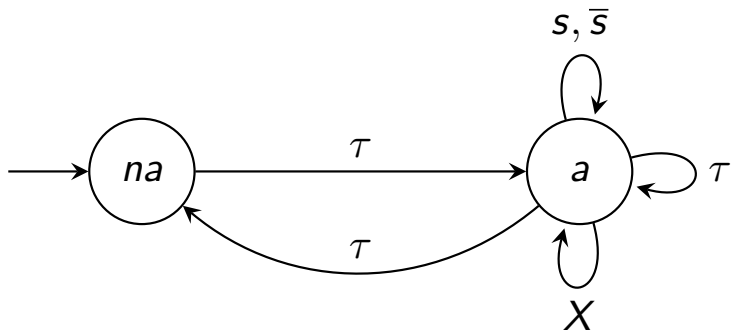
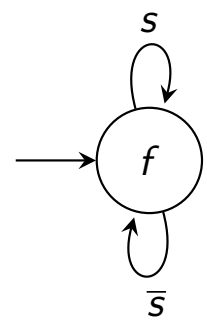
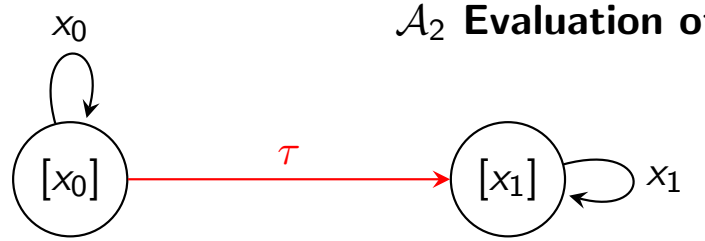


$\mathcal{A}_1$ **Appraisal**



$\mathcal{A}_2$ **Evaluation of stress**



$\mathcal{A}_3$ **Environment**

Modeling the transactional theory

Adding the environment: Refining $\mathcal{S}_1$ into $\mathcal{S}_2$

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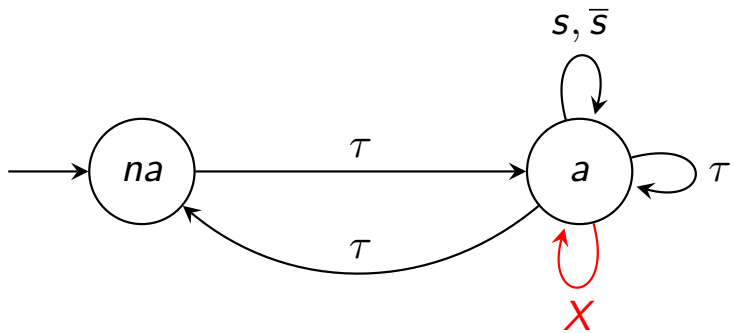
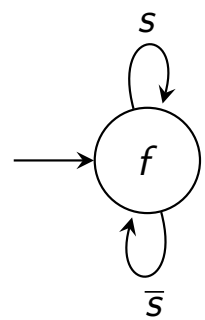
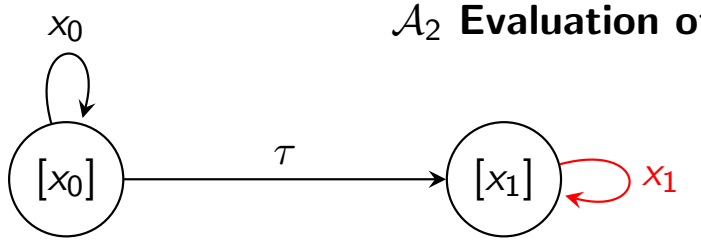


$\mathcal{A}_1$ **Appraisal**



$\mathcal{A}_2$ **Evaluation of stress**



$\mathcal{A}_3$ **Environment**

Modeling the transactional theory

Adding the environment: Refining $\mathcal{S}_1$ into $\mathcal{S}_2$

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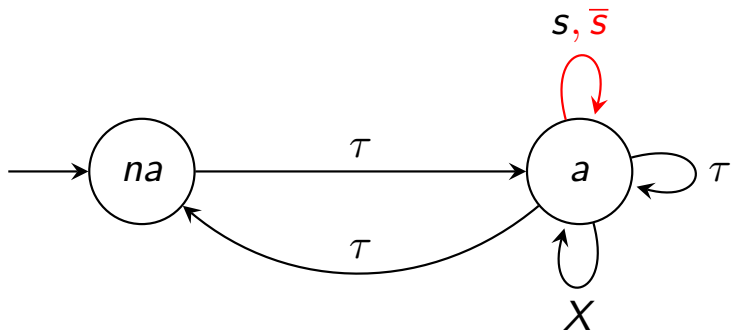
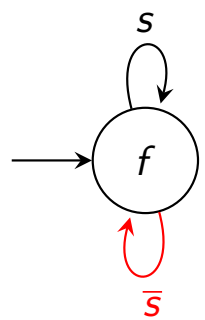
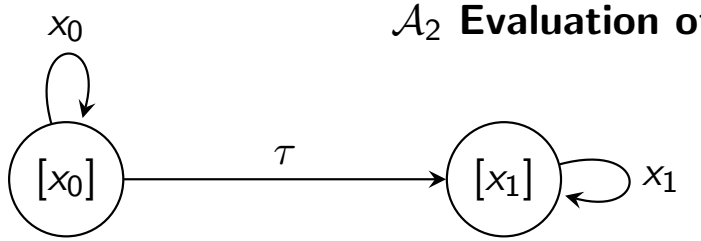
$(a, f, [x_1]) \xrightarrow{x_1} (a, f, [x_1]) \xrightarrow{\overline{s}} (a, f, [x_1])$



$\mathcal{A}_1$ **Appraisal**



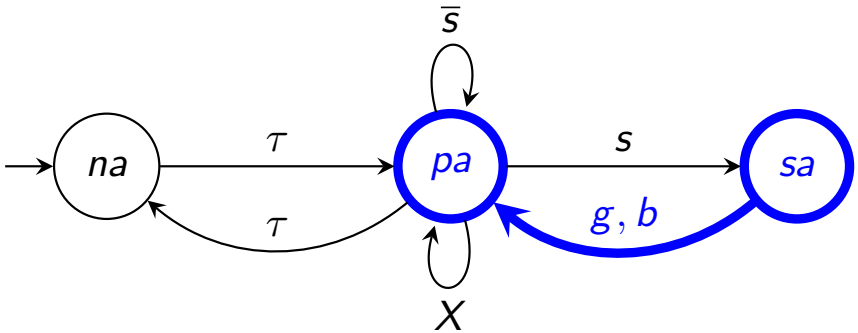
$\mathcal{A}_2$ **Evaluation of stress**



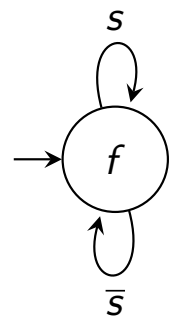
$\mathcal{A}_3$ **Environment**

Modeling the transactional theory

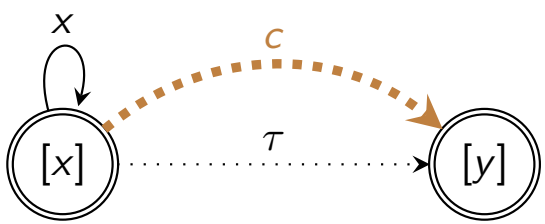
Adding primary appraisal, secondary appraisal and coping: refining $\mathcal{S}_2$ into $\mathcal{S}_3$



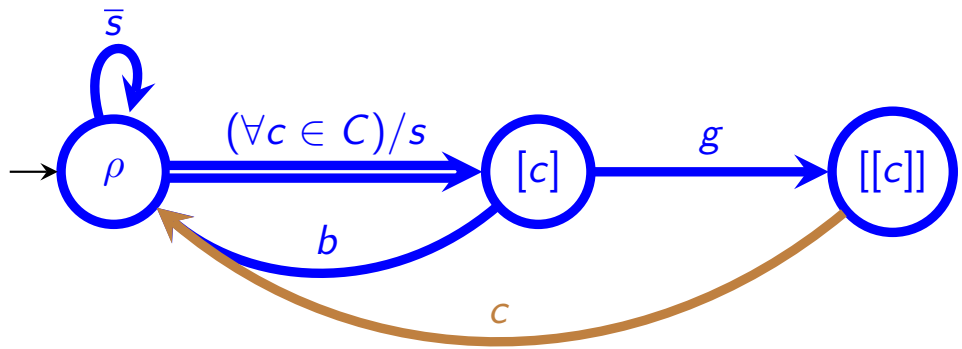
$\mathcal{A}_1$: Appraisal



$\mathcal{A}_2$: Calculating stress



$\mathcal{A}_3$: Environment



$\mathcal{A}_4$: Secondary appraisal and coping

Modeling the transactional theory

Adding primary appraisal, secondary appraisal and coping: refining $\mathcal{S}_2$ into $\mathcal{S}_3$

a person wakes up, perceives its environment, appraises the person-environment relationship as stressful, wonders if coping strategy c_1 would be beneficial, perceives c_1 as a bad strategy, wonders if coping strategy c_2 would be beneficial, perceives c_2 to be a good strategy, engages in coping efforts with strategy c_2, the environment changes, the person perceives the new environment, the person appraises the new person-environment relationship as non-stressful.

$(na, f, [x_0], \rho) \xrightarrow{\tau} (pa, f, [x_0], \rho) \xrightarrow{x_0} (pa, f, [x_0], \rho) \xrightarrow{s}$
$(sa, f, [x_0], [c_1]) \xrightarrow{b} (pa, f, [x_0], \rho) \xrightarrow{s} (sa, f, [x_0], [c_2]) \xrightarrow{g}$
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$(pa, f, [x_1], \rho).$

Modeling the transactional theory

Adding primary appraisal, secondary appraisal and coping: refining $\mathcal{S}_2$ into $\mathcal{S}_3$

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Modeling the transactional theory

Adding primary appraisal, secondary appraisal and coping: refining $\mathcal{S}_2$ into $\mathcal{S}_3$

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$(pa, f, [x_1], \rho) \xrightarrow{\bar{s}} (pa, f, [x_1], \rho).$

Modeling the transactional theory

Adding primary appraisal, secondary appraisal and coping: refining $\mathcal{S}_2$ into $\mathcal{S}_3$

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Modeling the transactional theory

Adding primary appraisal, secondary appraisal and coping: refining $\mathcal{S}_2$ into $\mathcal{S}_3$

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Modeling the transactional theory

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Modeling the transactional theory

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Modeling the transactional theory

Adding primary appraisal, secondary appraisal and coping: refining $\mathcal{S}_2$ into $\mathcal{S}_3$

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Modeling the transactional theory

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Modeling the transactional theory

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Modeling the transactional theory

Adding commitments: refining $\mathcal{S}_3$ into $\mathcal{S}_4$

"Commitments express what is important to the person, what has meaning for him or her." (Lazarus & Folkman, 1984)
Commitments: function

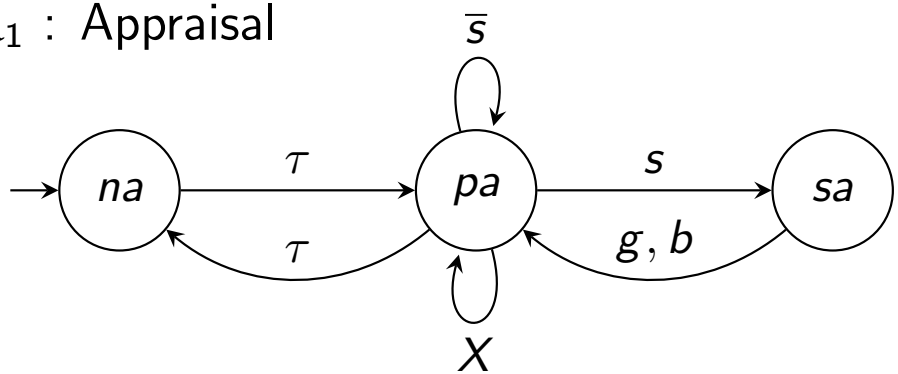
$$\varphi : X \to \{0, 1\}$$

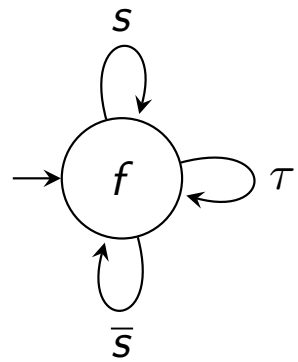
Person is stressed $\iff \varphi(x) = 0$
Some coping strategies affect commitments: φ can change.

Modeling the transactional theory

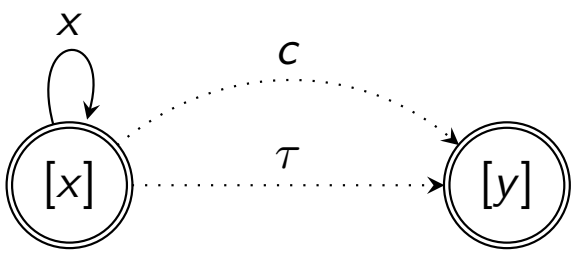
Adding commitments: refining $\mathcal{S}_3$ into $\mathcal{S}_4$

$\mathcal{A}_1$: Appraisal

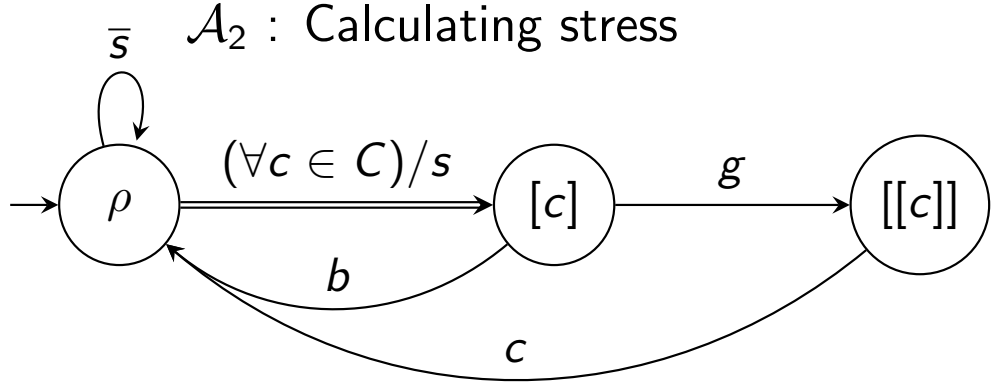


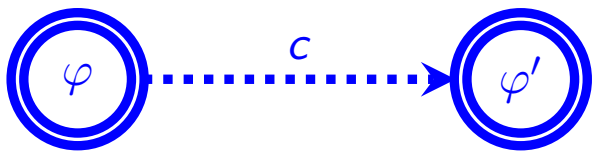


$\mathcal{A}_2$: Calculating stress



$\mathcal{A}_3$: Environment





$\mathcal{A}_5$: Internal parameters

$\mathcal{A}_4$: Secondary appraisal and coping

Modeling the transactional theory

Example:

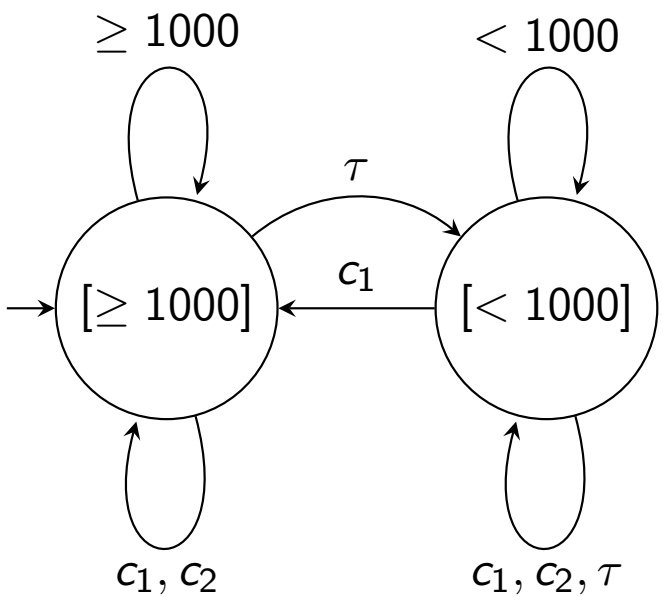
Person's relationship with money: *"It's important for me to have enough money. I want to feel like I'm safe financially. Enough money for me is having more than 1000 euros in my bank account. Right now I have enough money. Sometimes people steal money from my bank account and I have no money left. As a way to make myself feel better, I try to save a lot of money each month, and I try to think that money is not so important"*

$X = \{\geq 1000, < 1000\}$, (more than 1000 euros or less than 1000 euros)
$\varphi : X \to \{0, 1\}$ $\varphi(\geq 1000) = 1$ and $\varphi(< 1000) = 0$
$\Phi = \{\varphi, \mathbf{1} - \varphi, \mathbf{1}, \mathbf{0}\}$, ($\mathbf{1}$ always 1).
c_1 : "saving money"
c_2 : "trying to think money is not important"
One τ-transition: "Sometimes people steal money from my bank account and I have no money left"

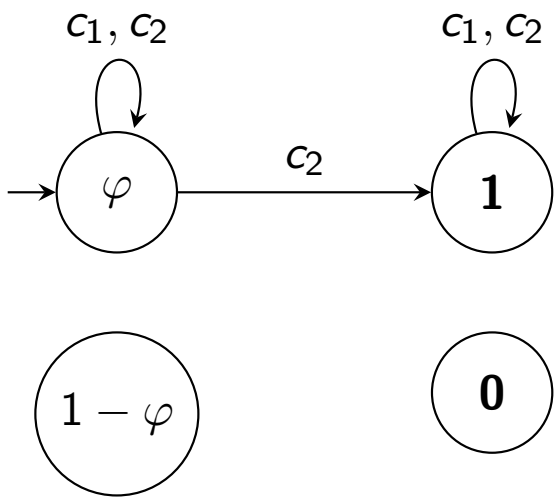
Modeling the transactional theory

Example:

c_1 : "saving money"
c_2 : "trying to think money is not important"
One τ-transition: "Sometimes people steal money from my bank account and I have no money let"



$\mathcal{A}_3$: Environment



$\mathcal{A}_5$: Internal parameters

Modeling the transactional theory

Adding more modules : $M_1, M_2, M_3 \ldots$

- M_1 : Imagining a course of actions and its results
- M_2 : Memorising coping strategies
- M_3 : Decision-making theories
- M_4 : Calculating the stress-level based on the goals, values and believes of the individual
- ...
- Any compatible cognitive theory!

6. Verification

Verification

Modeling appraisal : System $\mathcal{S}_1$

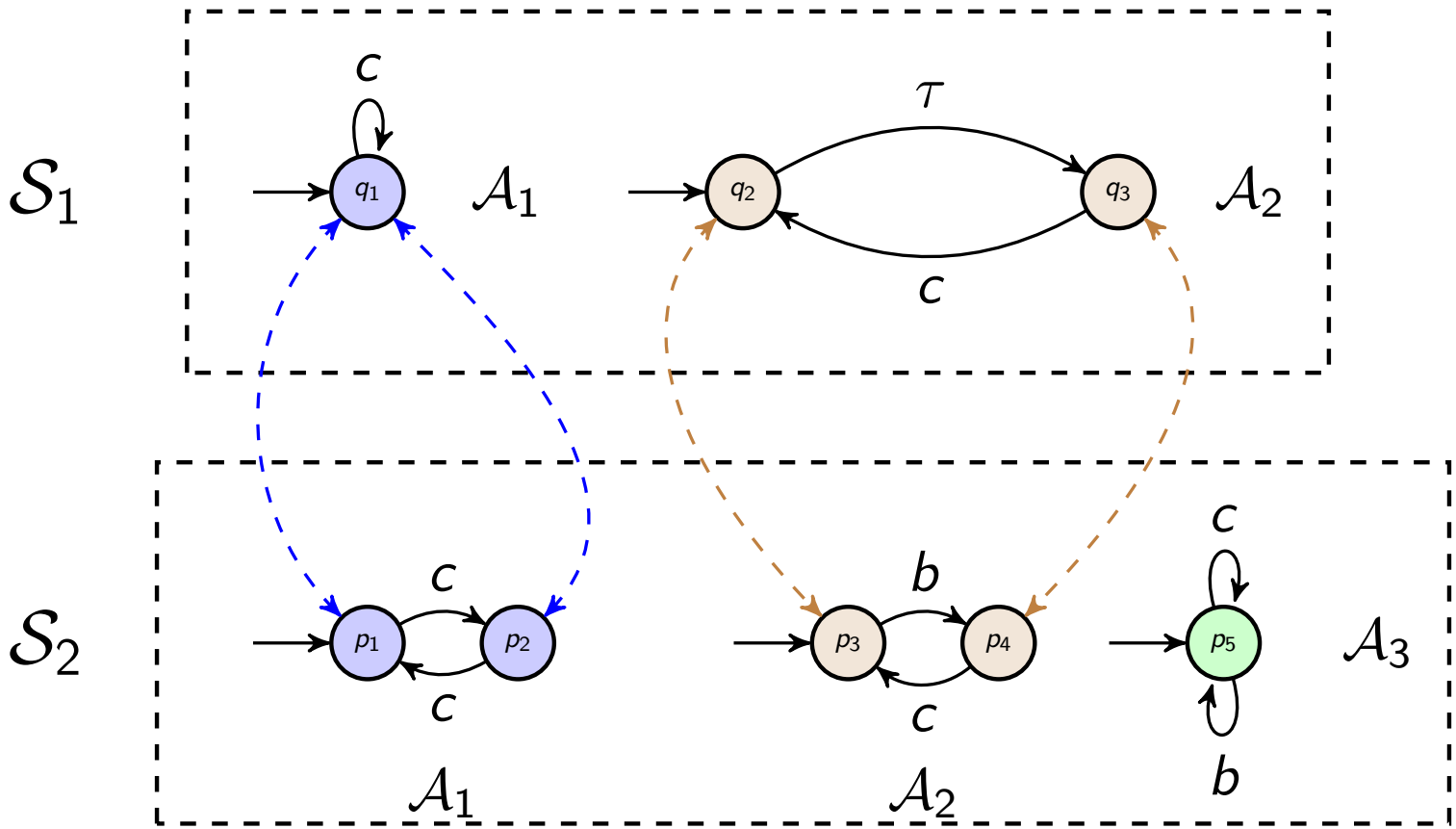
"Cognitive appraisal is an evaluative process that determines why and to what extent a particular transaction or series of transactions between the person and the environment is stressful." "Cognitive appraisal can be most readily understood as the process of categorizing an encounter, and its various facets, with respect to its significance for well-being. (...) Rather, it is largely evaluative, focused on meaning or significance, and takes place continuously during waking life."(Lazarus & Folkman, 1984)

$$G(a \iff aw)$$
$$G(a \implies aW(na \vee s \vee \overline{s}))$$

7. Mathematical transformations for theory-building

Mathematical transformations for theory-building

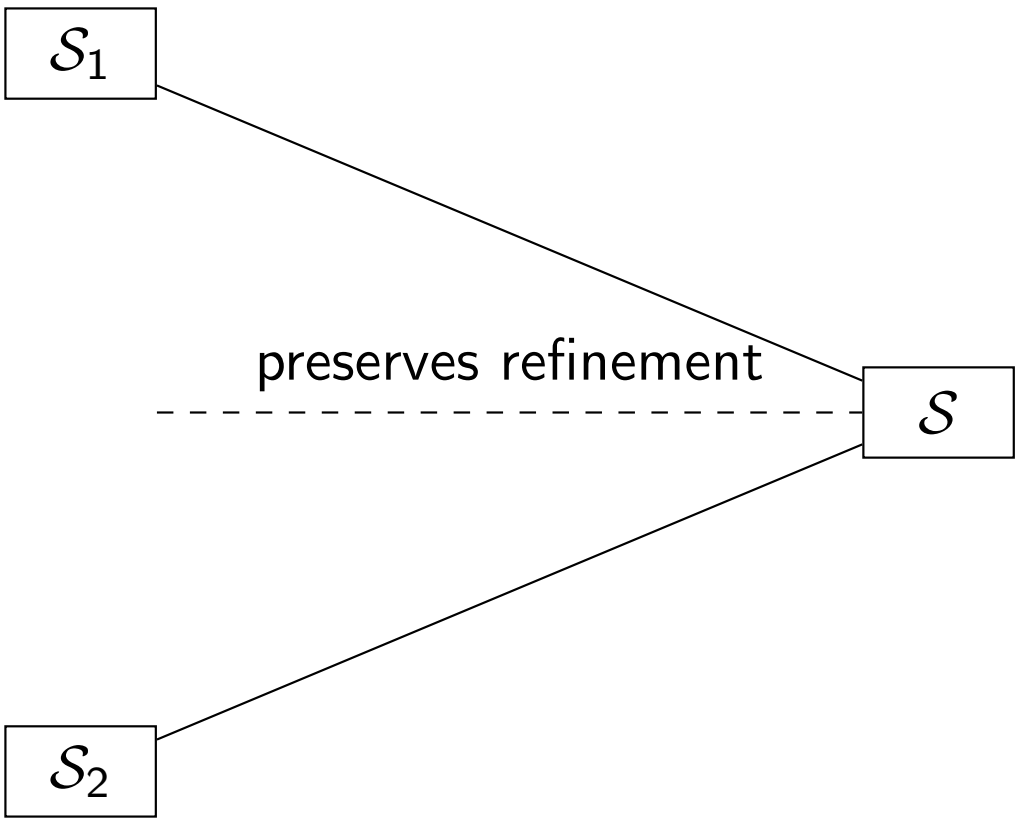
3 types of refinement



Mathematical transformations for theory-building

Merging: comparing and combining theories

- Preserves refinement
- When there is no common state: juxtaposition
- Otherwise, verifying compatibility and merging



8. Perspectives & conclusions

Perspectives & conclusions

- Further develop the methodology
- Formalise other theories: GWT, active inference, memory, appraisal theories...
- Formally compare different theories of the same field
- Create a big modular theory by merging different theories

Perspectives & conclusions

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