Advances in the Development of Non-Utility-Maximizing Models of Choice Behavior in Transportation Research

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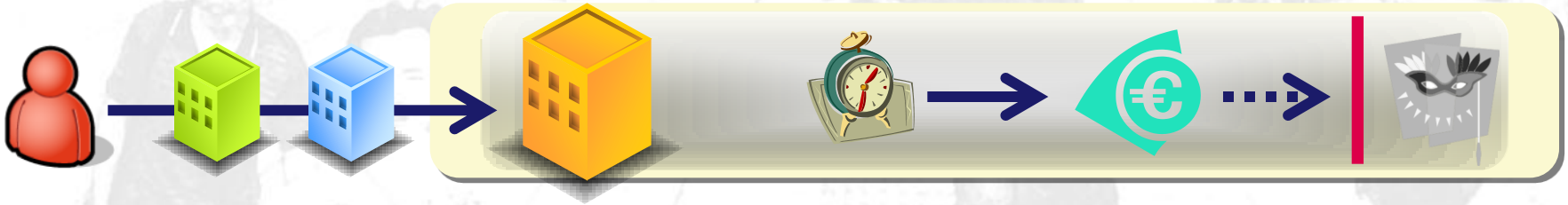
Limitations

- Rational utility-maximising choice models may not sufficiently nor adequately represent real *decision processes* in that they assume
  - Evaluating utilities for each alternative
  - Trading off utilities of all factors
  - Choosing the alternative with the highest utility

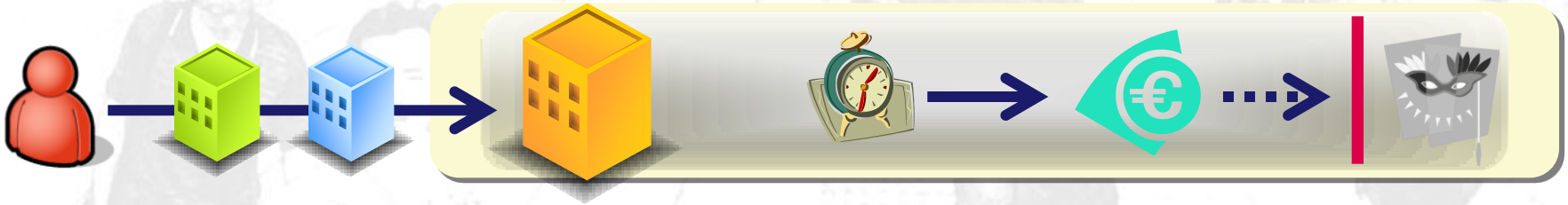
Background

- Principles of bounded rationality could be more appropriate.
  - Limits in cognitive and computational ability
  - Satisficing behavior
  - Incomplete information
  - Simplifying (heuristic) decision rules
  - Non-cognitively driven choices



Aim presentation

- Discuss some examples of recent work in our group to formulate, estimate and apply models of bounded rationality, metal representation and hybrid choice drivers.
  - Heterogeneous heuristic model (HHR model)
  - Mental representation
  - Hybrid affective-cognitive model



HETEROGENEOUS HEURISTIC MODEL

Behavioral Heterogeneity

Is usually captured in discrete choice models in terms of

(1) Unobservable utility (e.g., MNL)

$$u_i = \sum_j \beta_j x_{ij} + \varepsilon_i$$

(2) Parameter distribution (mixed logit)

$$u_i = \sum_j \beta_{j1} x_{ij} + \varepsilon_i \quad \sim p_1$$

...

(3) Latent class

$$u_i = \sum_j \beta_{jN} x_{ij} + \varepsilon_i \quad \sim p_N$$

$$\sum_n p_n = 1$$

Specification Problems

Choose the alternative with the highest utility

$$i \mid \sum_j \beta_j x_{ij} + \varepsilon_i \geq \sum_j \beta_j x_{kj} + \varepsilon_k, \ \forall k \neq i$$

(1) Infinitely small **decision criterion** (utility difference) is used, little is considered about criterion variability.

(2) Comparisons are directly based on parametric utilities. However, preference was originally defined on **rank orders**.

Heterogeneous Heuristic Model

1

BR model

- To develop and test a model of travel behavior, based on principles of Bounded Rationality, using real-world behavioral data.

2

Heterogeneity

- To develop a modeling approach that allows for decision heterogeneity in terms of individual decision *strategies*.

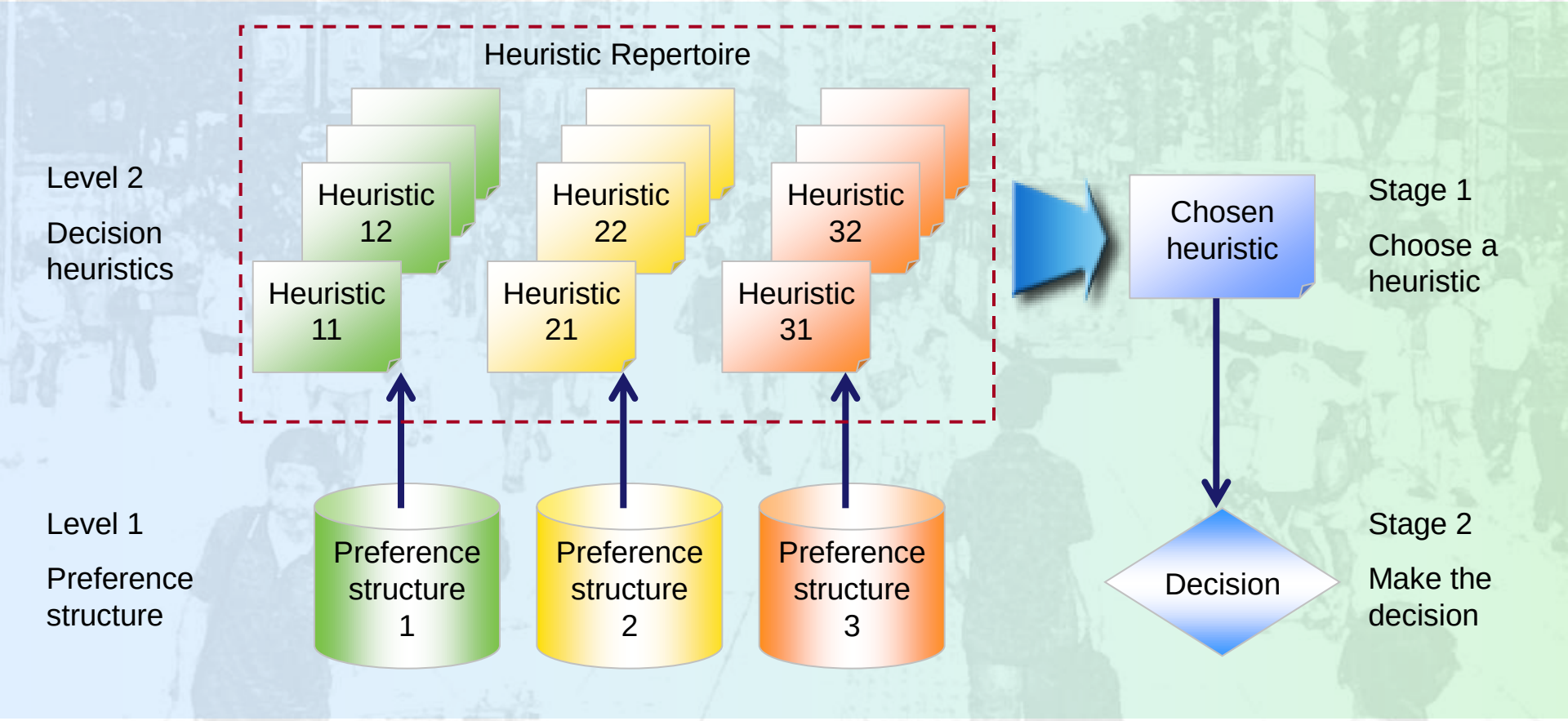
3

Time

- To examine time-dependent aspects of travel behavior.

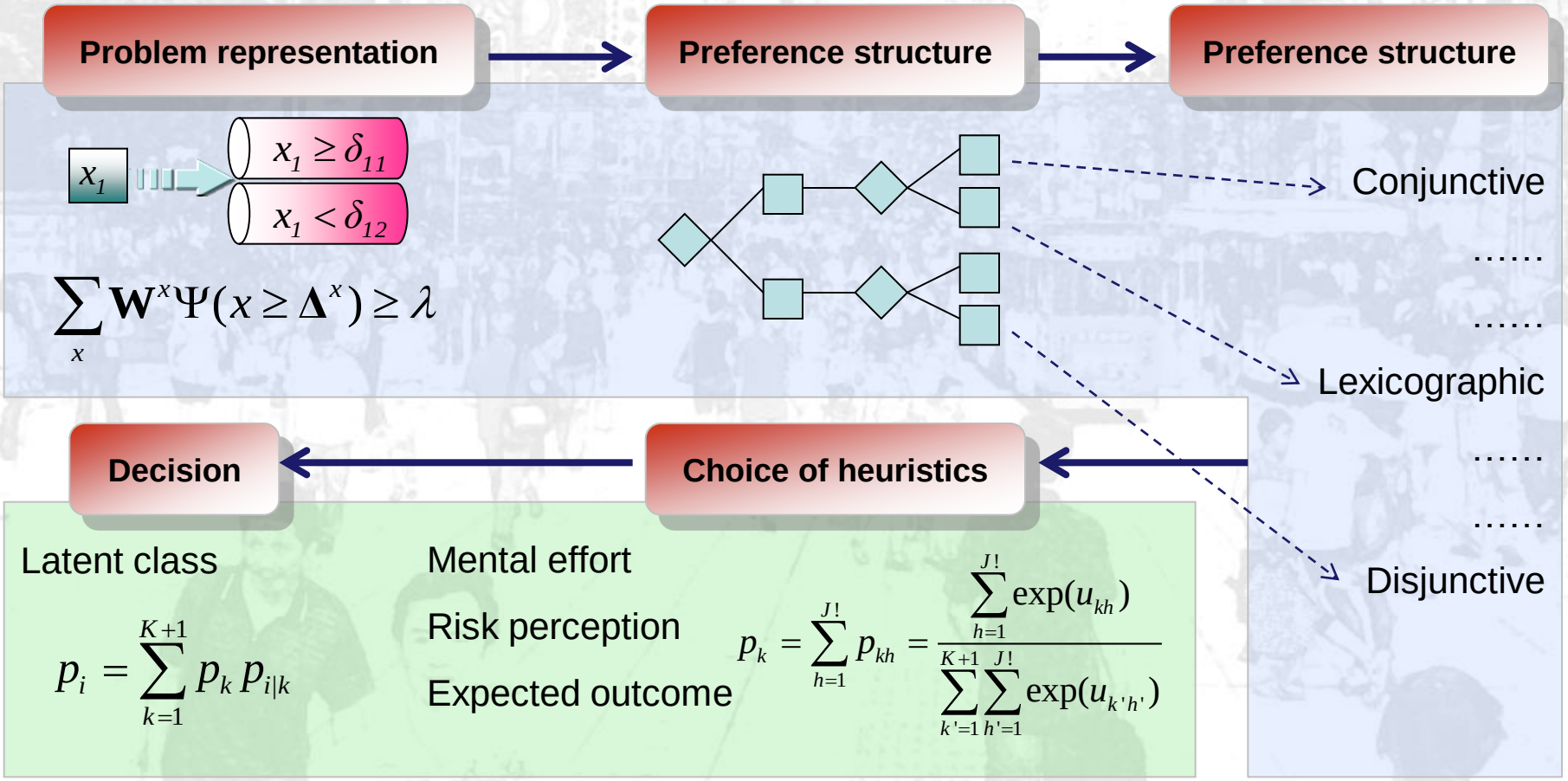
Conceptual Framework

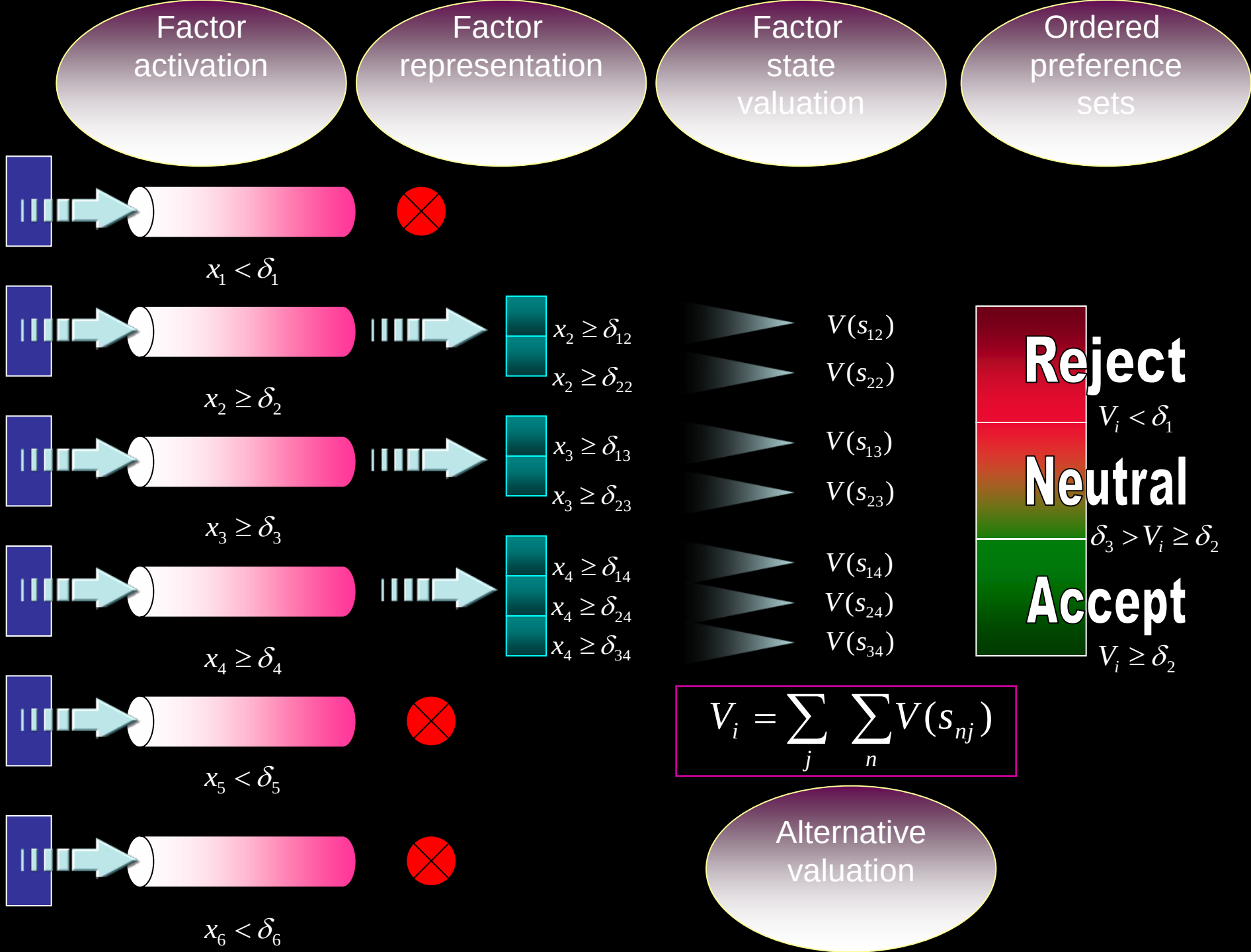
HHM is based on a two-level two-stage theoretical construct.

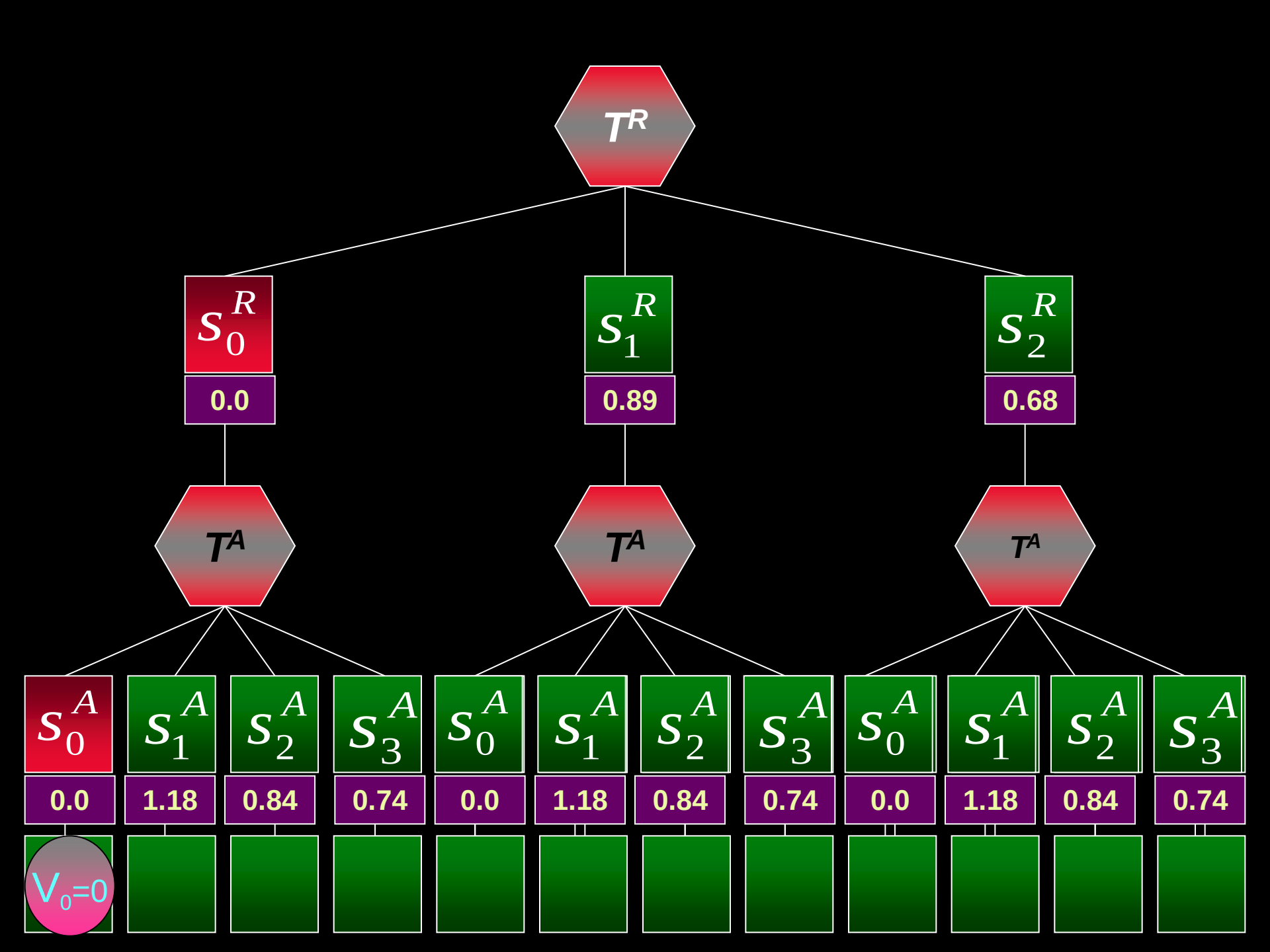


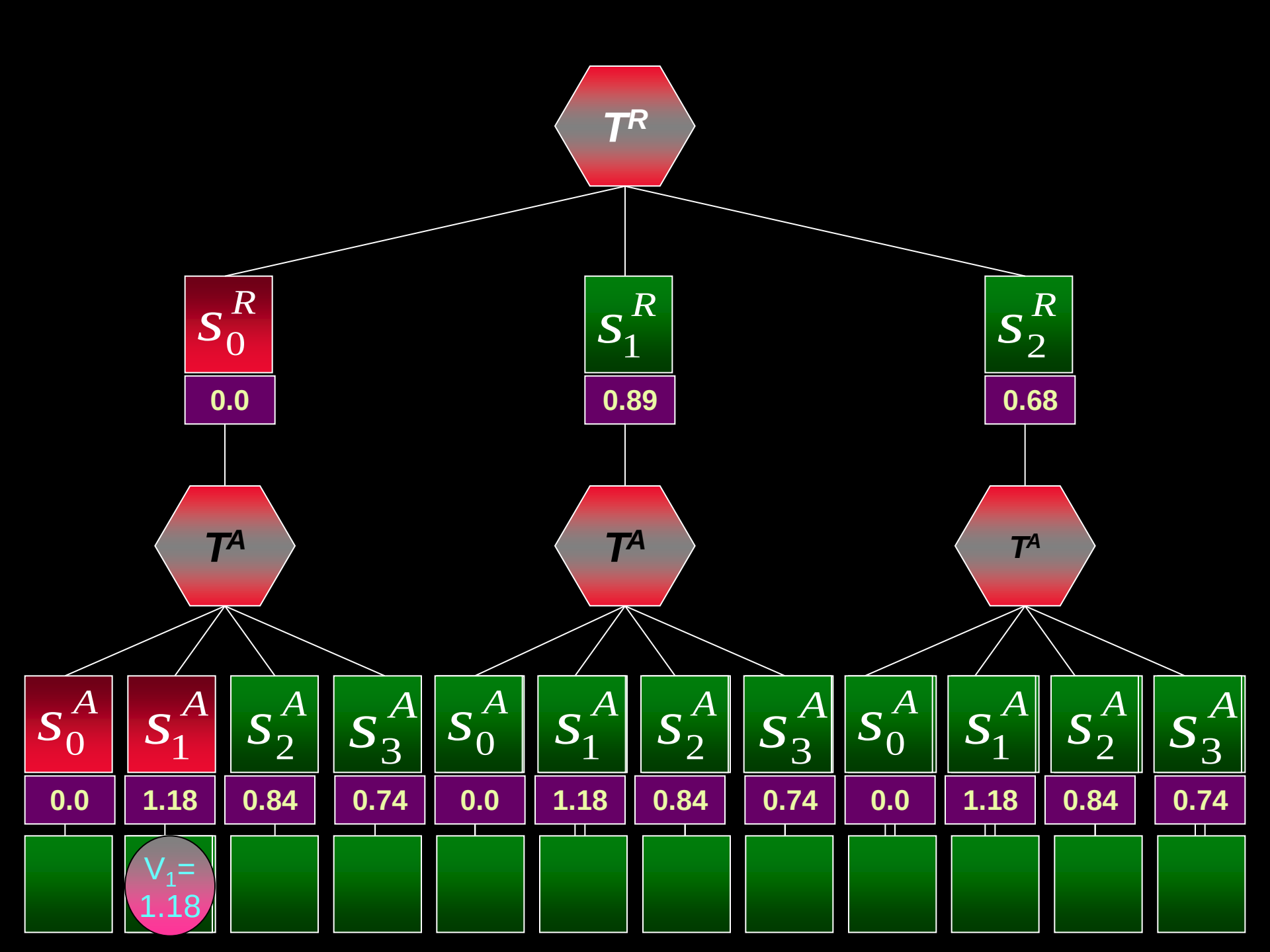
Conceptual Framework

- For satisficing decision and comparative choice




Factor activation
Factor representation
Factor state valuation
Ordered preference sets
$x_1 < \delta_1$
$x_2 \geq \delta_2$
$x_3 \geq \delta_3$
$x_4 \geq \delta_4$
$x_5 < \delta_5$
$x_6 < \delta_6$
$x_2 \geq \delta_{12}$
$x_2 \geq \delta_{22}$
$x_3 \geq \delta_{13}$
$x_3 \geq \delta_{23}$
$x_4 \geq \delta_{14}$
$x_4 \geq \delta_{24}$
$x_4 \geq \delta_{34}$
$V(s_{12})$
$V(s_{22})$
$V(s_{13})$
$V(s_{23})$
$V(s_{14})$
$V(s_{24})$
$V(s_{34})$
Reject
$V_i < \delta_1$
Neutral
$\delta_3 > V_i \geq \delta_2$
Accept
$V_i \geq \delta_2$
$V_i = \sum_j \sum_n V(s_{nj})$
Alternative valuation


T^R
s_0^R
s_1^R
s_2^R
0.0
0.89
0.68
T^A
T^A
T^A
s_0^A s_1^A s_2^A s_3^A
s_0^A s_1^A s_2^A s_3^A
s_0^A s_1^A s_2^A s_3^A
0.0 1.18 0.84 0.74
0.0 1.18 0.84 0.74
0.0 1.18 0.84 0.74
V_0=0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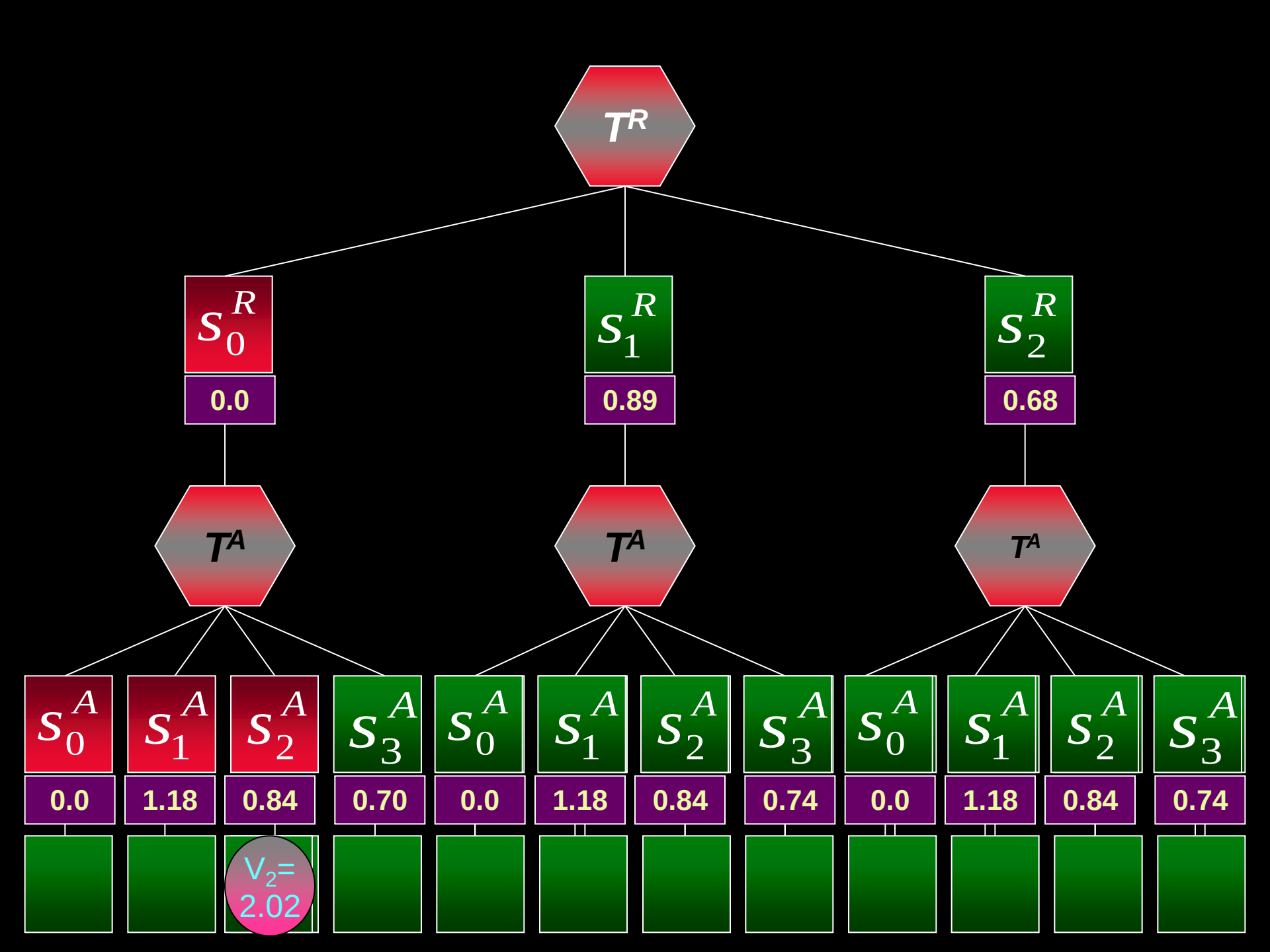
s_1^R
0.89
s_2^R
0.68
T^A
T^A
T^A
s_0^A 0.0
s_1^A 1.18
s_2^A 0.84
s_3^A 0.74
s_0^A 0.0
s_1^A 1.18
s_2^A 0.84
s_3^A 0.74
s_0^A 0.0
s_1^A 1.18
s_2^A 0.84
s_3^A 0.74
V_1= 1.18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s_1^R
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s_2^R
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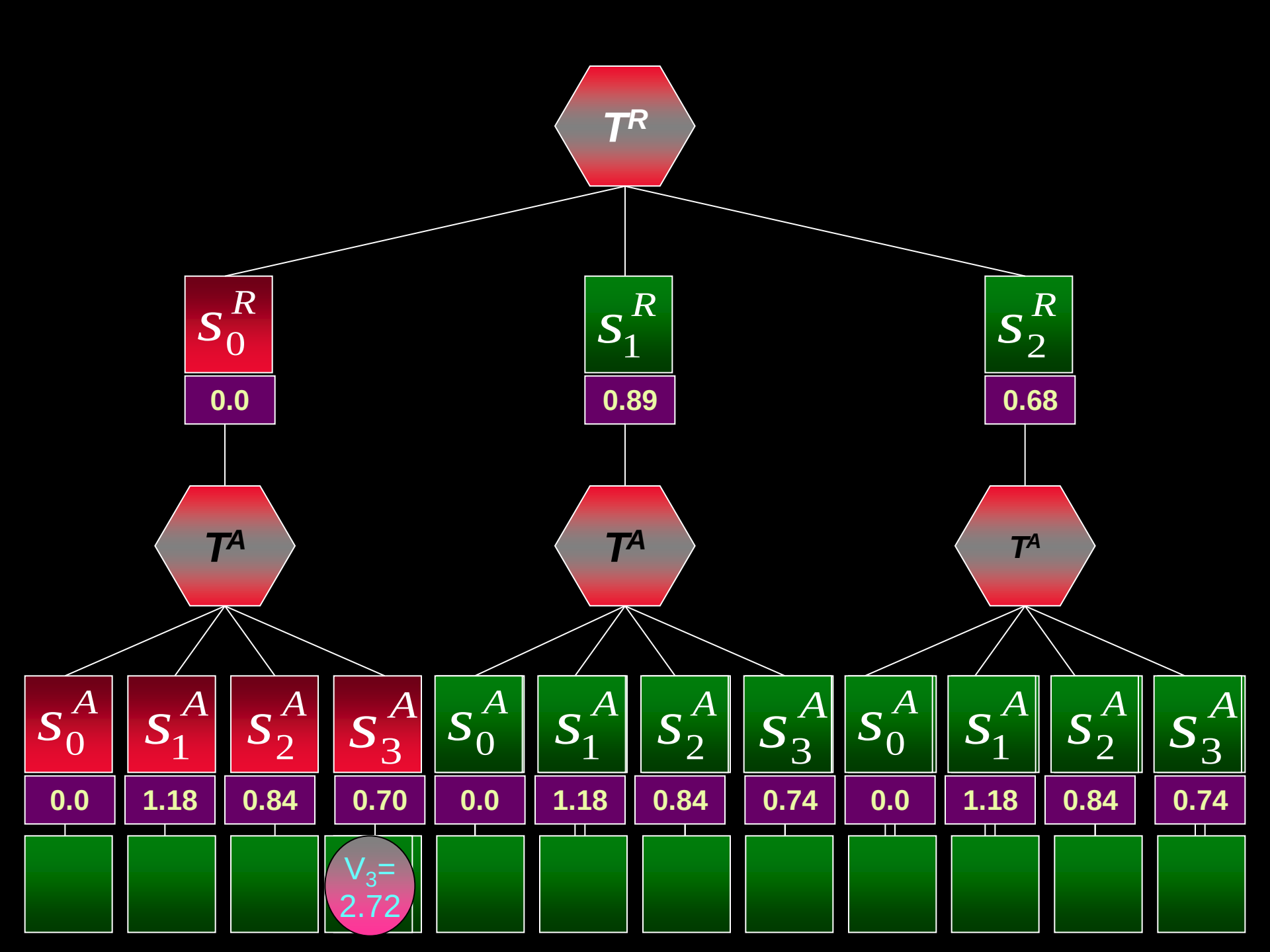
T^A
T^A
T^A
s_0^A 0.0
s_1^A 1.18
s_2^A 0.84
s_3^A 0.70
s_0^A 0.0
s_1^A 1.18
s_2^A 0.84
s_3^A 0.74
s_0^A 0.0
s_1^A 1.18
s_2^A 0.84
s_3^A 0.74
V_2= 2.02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s_2^R
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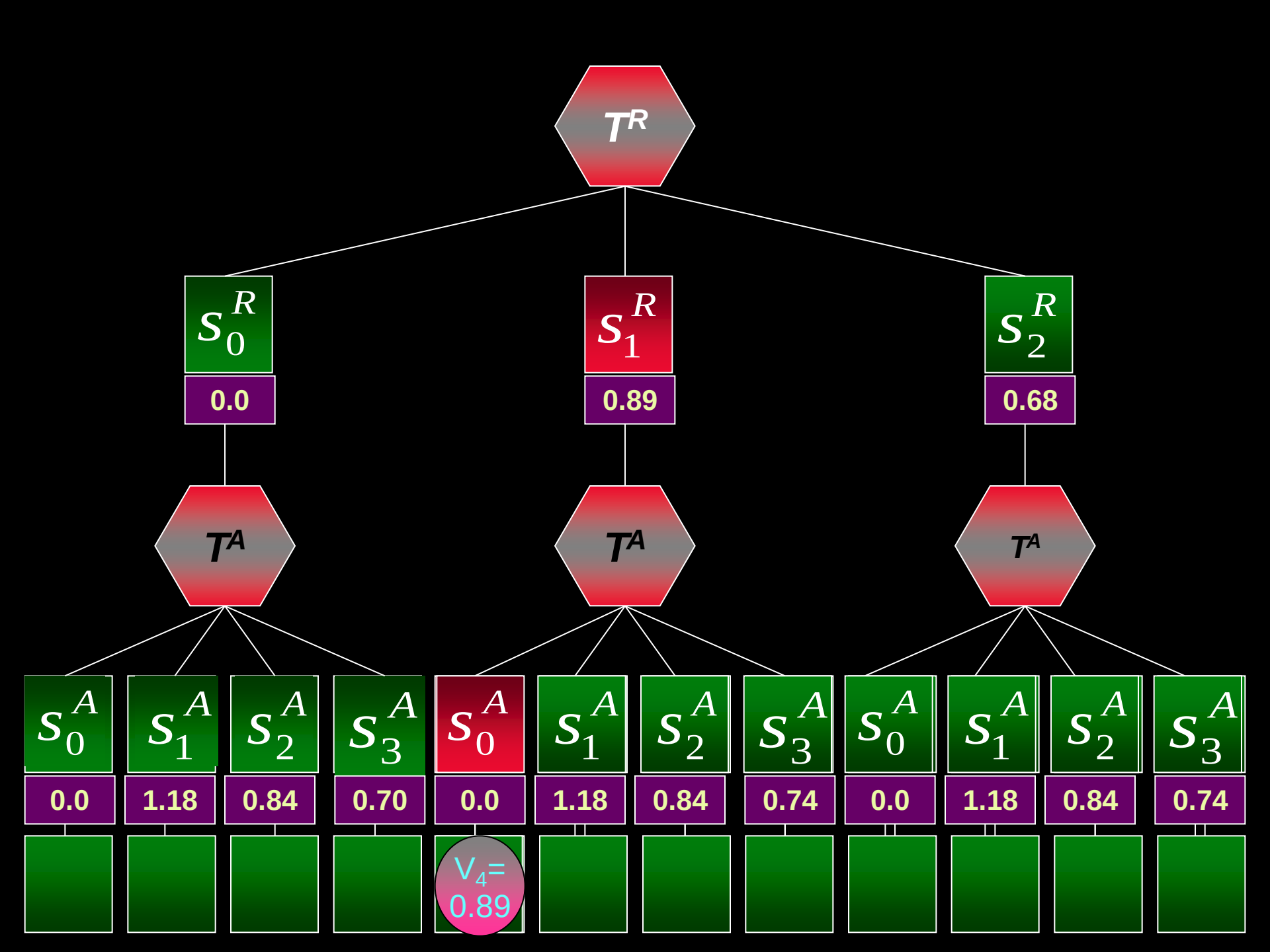
T^A
T^A
s_0^A 0.0
s_1^A 1.18
s_2^A 0.84
s_3^A 0.70
s_0^A 0.0
s_1^A 1.18
s_2^A 0.84
s_3^A 0.74
s_0^A 0.0
s_1^A 1.18
s_2^A 0.84
s_3^A 0.74
V_3= 2.72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T^A
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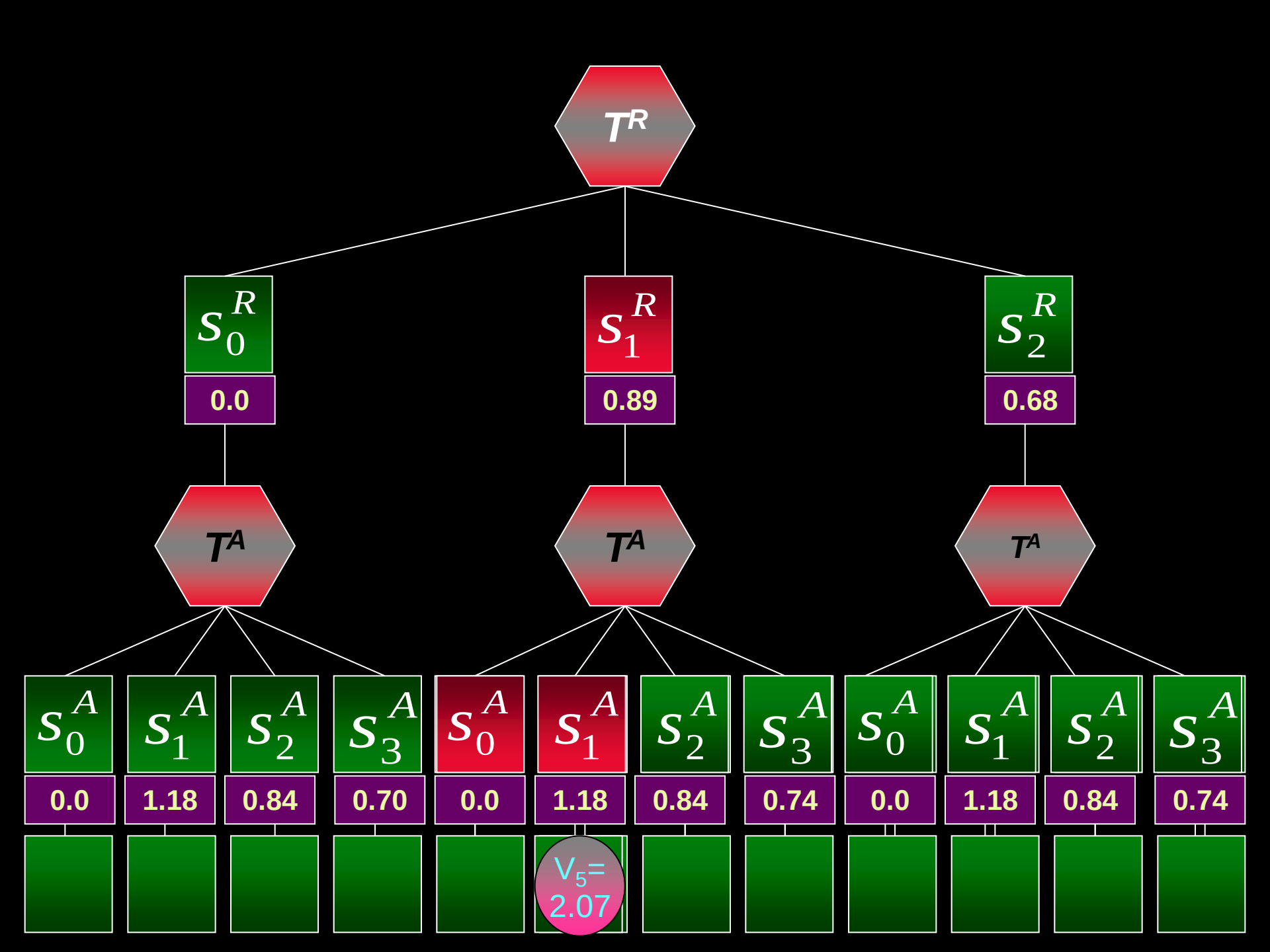
s_0^A s_1^A s_2^A s_3^A
s_0^A s_1^A s_2^A s_3^A
0.0 1.18 0.84 0.70
0.0 1.18 0.84 0.74
0.0 1.18 0.84 0.74
V_4= 0.89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s_1^R
s_2^R
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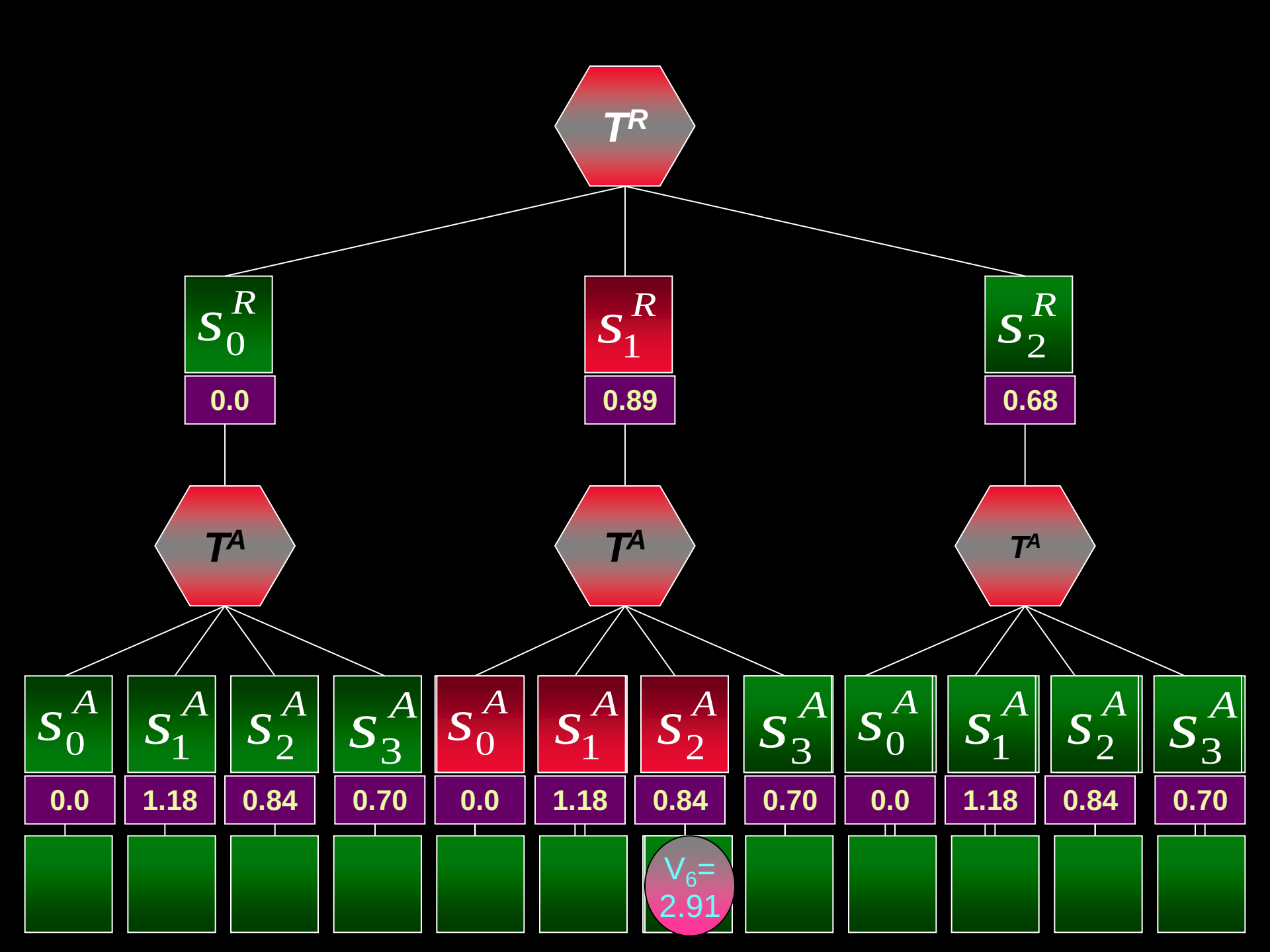
0.89
0.68
T^A
T^A
T^A
s_0^A s_1^A s_2^A s_3^A
s_0^A s_1^A s_2^A s_3^A
s_0^A s_1^A s_2^A s_3^A
0.0 1.18 0.84 0.70
0.0 1.18 0.84 0.74
0.0 1.18 0.84 0.74
V_5= 2.07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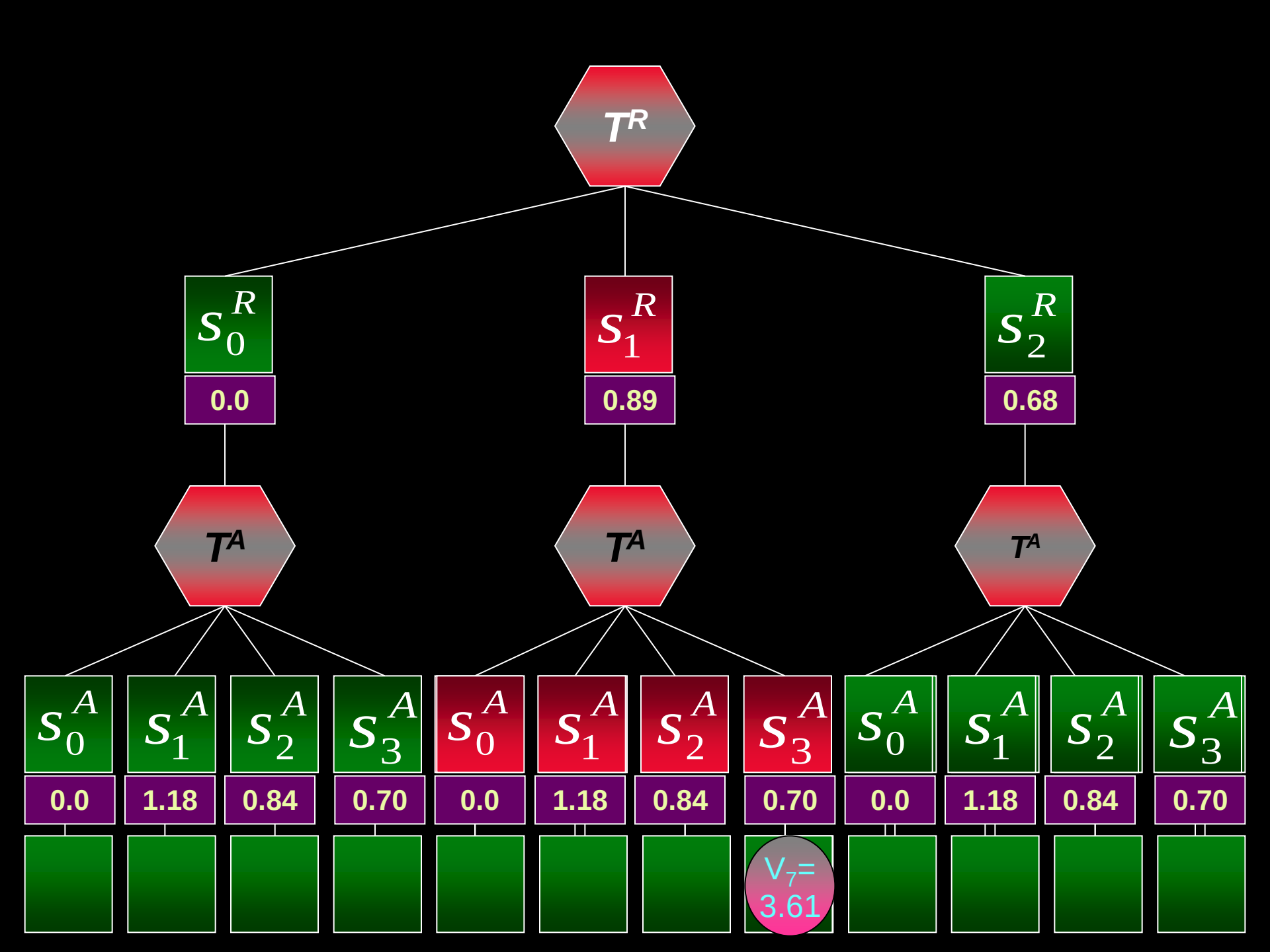
s_0^R
s_1^R
s_2^R
0.0
0.89
0.68
T^A
T^A
T^A
s_0^A s_1^A s_2^A s_3^A
s_0^A s_1^A s_2^A s_3^A
s_0^A s_1^A s_2^A s_3^A
0.0 1.18 0.84 0.70
0.0 1.18 0.84 0.70
0.0 1.18 0.84 0.70
V_6= 2.91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s_0^R
s_1^R
s_2^R
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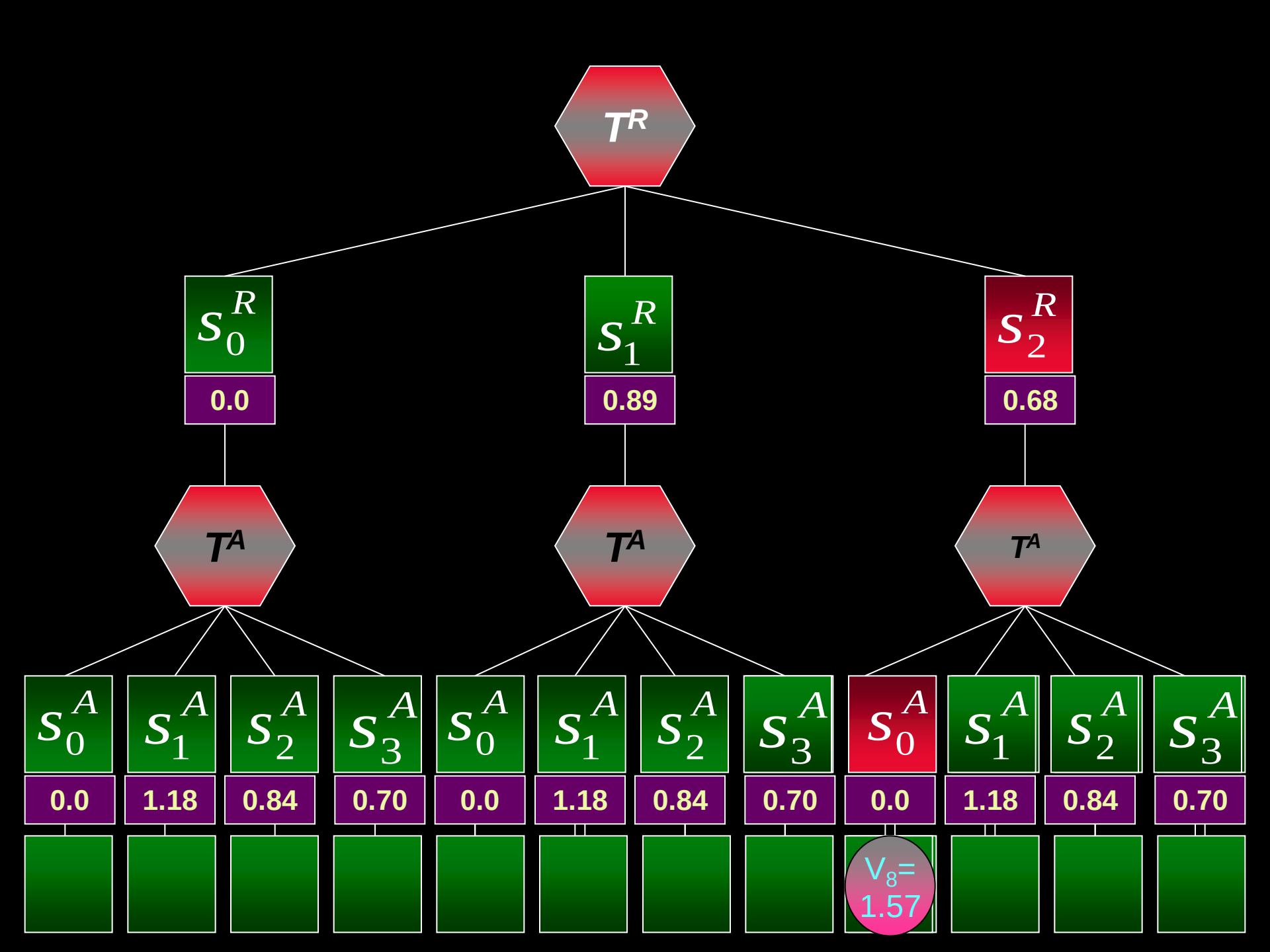
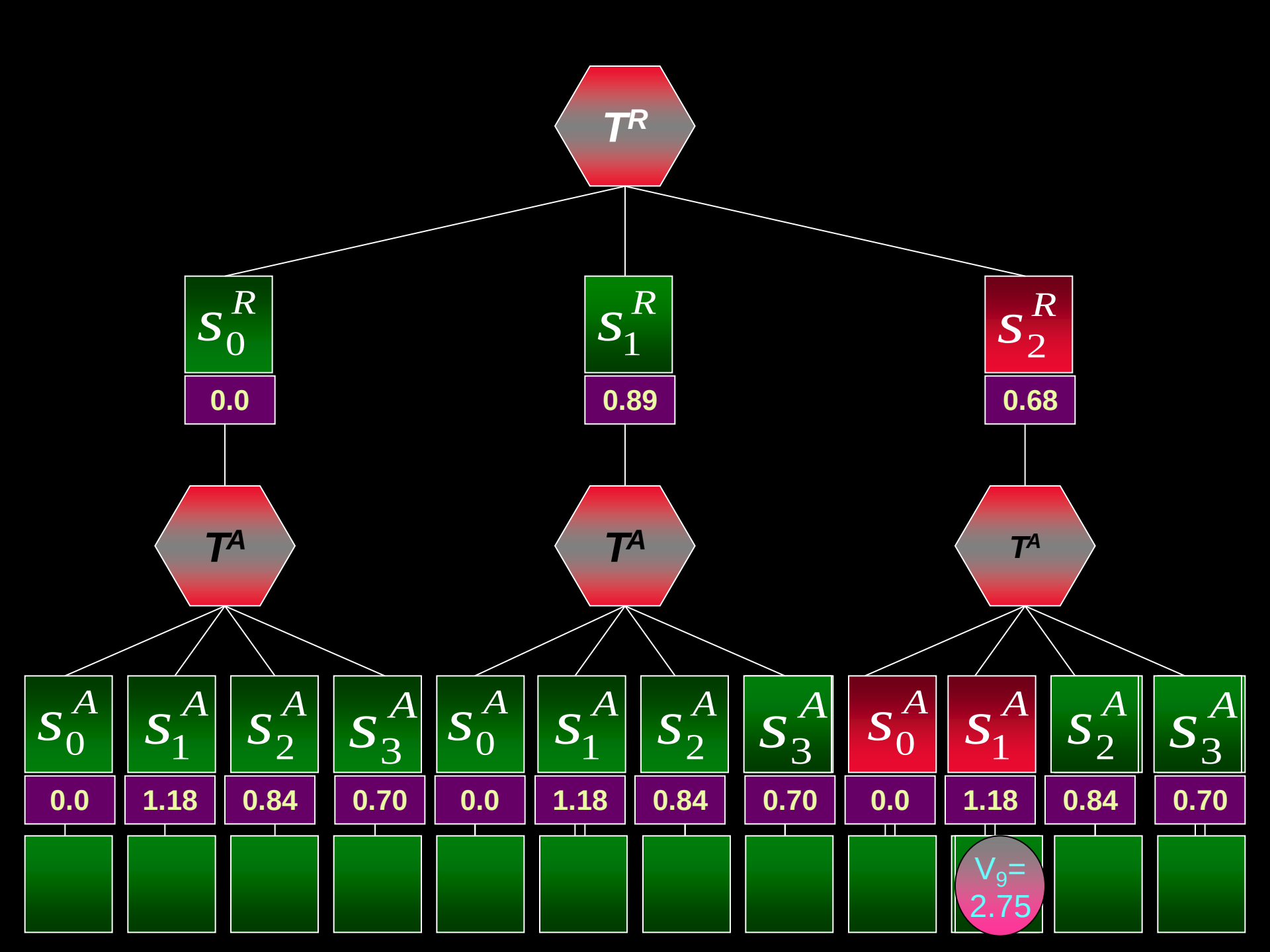
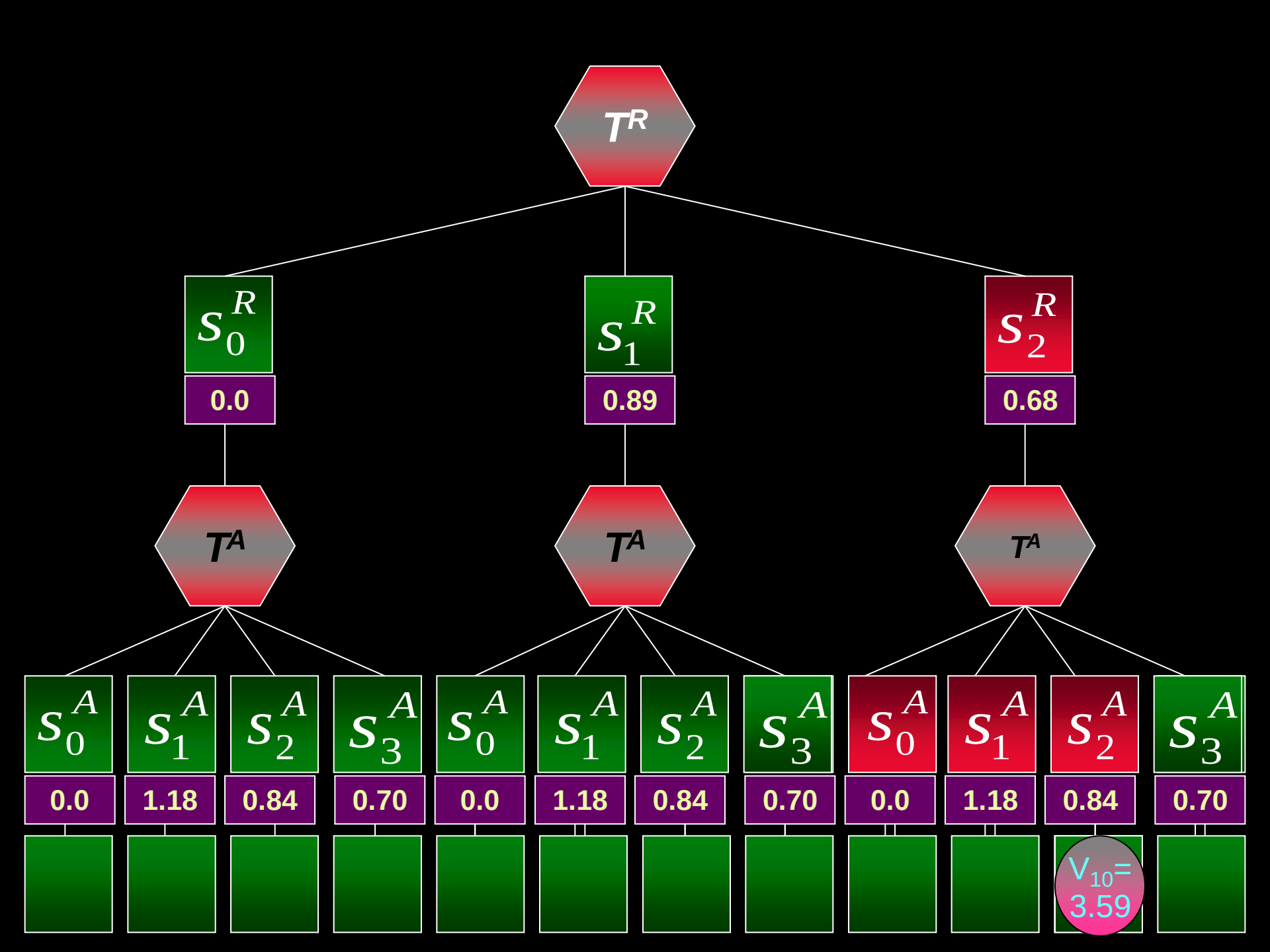
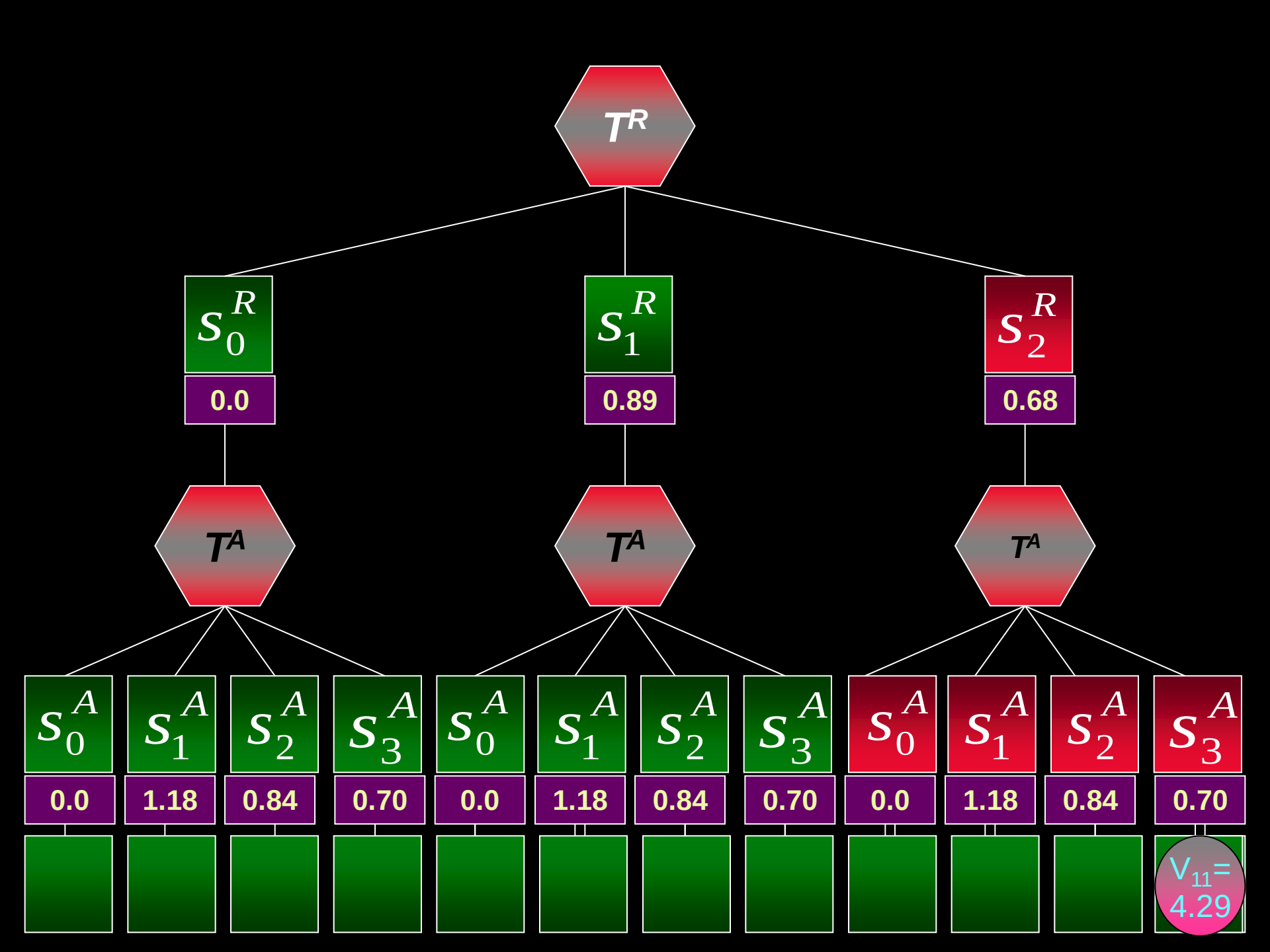
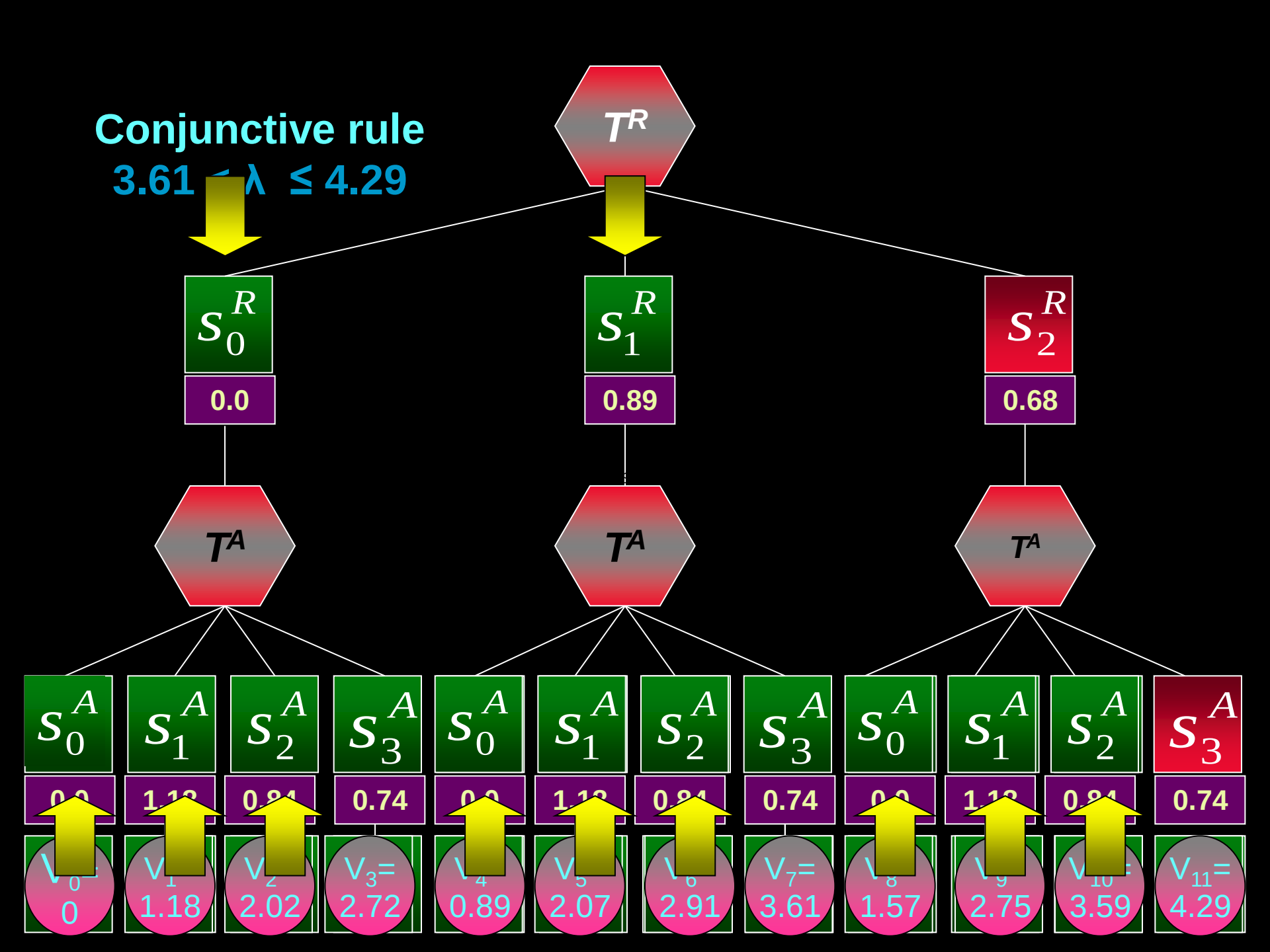
0.89
0.68
T^A
T^A
T^A
s_0^A s_1^A s_2^A s_3^A
s_0^A s_1^A s_2^A s_3^A
s_0^A s_1^A s_2^A s_3^A
0.0 1.18 0.84 0.70
0.0 1.18 0.84 0.70
0.0 1.18 0.84 0.70
V_7= 3.61

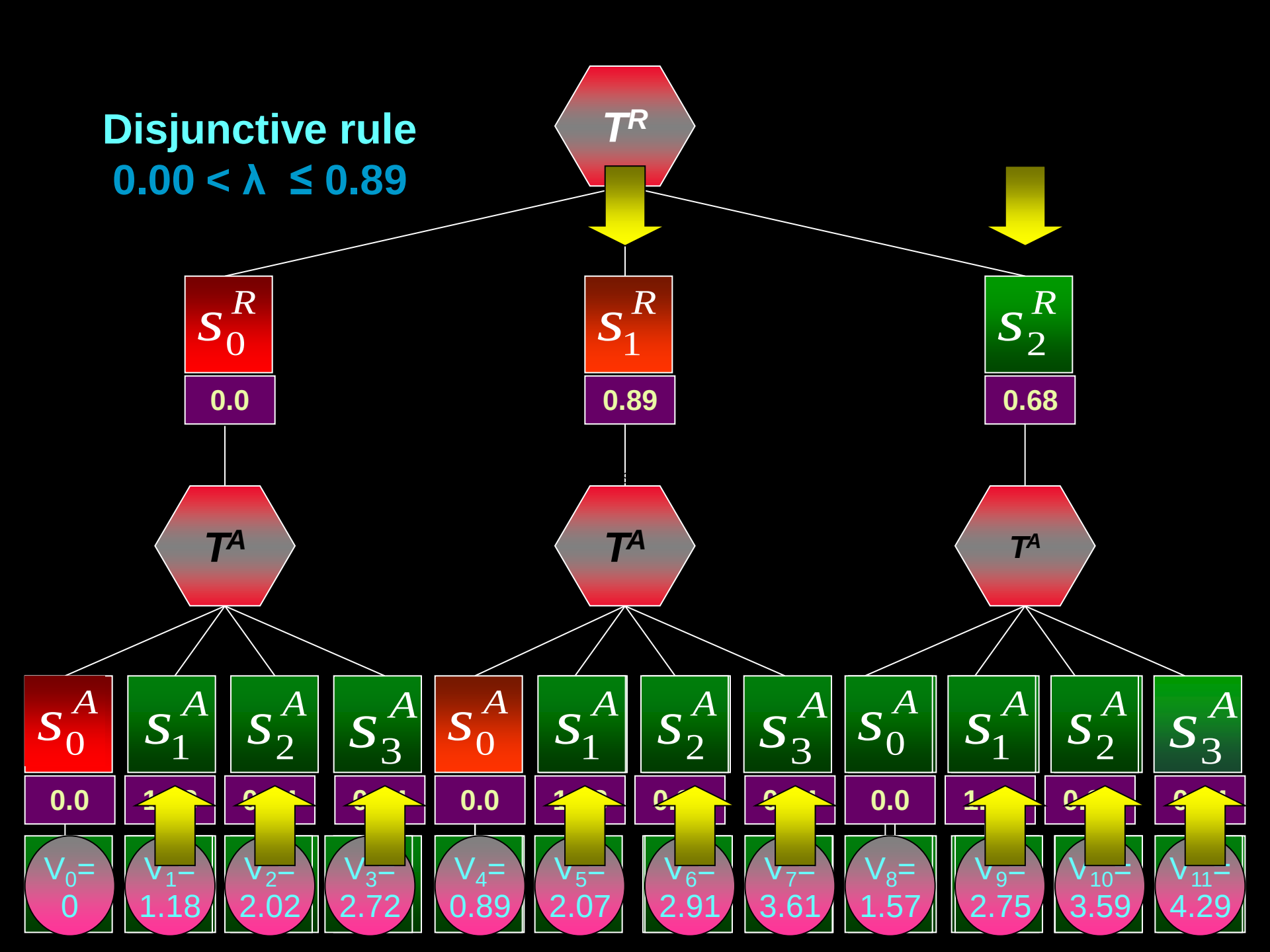

T^R
s_0^R
s_1^R
s_2^R
0.0
0.89
0.68
T^A
T^A
T^A
s_0^A s_1^A s_2^A s_3^A
s_0^A s_1^A s_2^A s_3^A
s_0^A s_1^A s_2^A s_3^A
0.0 1.18 0.84 0.70
0.0 1.18 0.84 0.70
0.0 1.18 0.84 0.70
V_8= 1.57

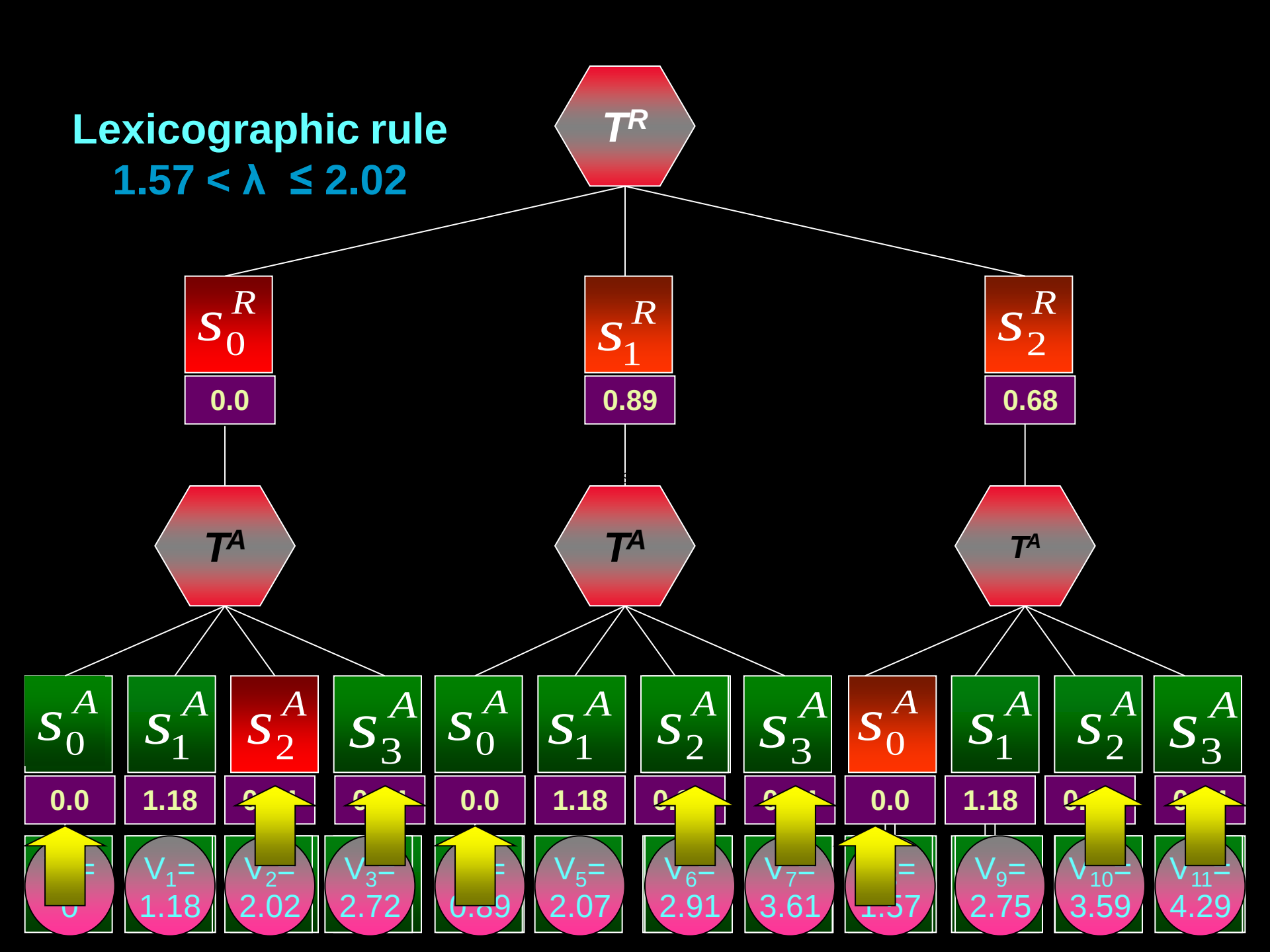

T^R
s_0^R
s_1^R
s_2^R
0.0
0.89
0.68
T^A
T^A
T^A
s_0^A s_1^A s_2^A s_3^A
s_0^A s_1^A s_2^A s_3^A
s_0^A s_1^A s_2^A s_3^A
0.0 1.18 0.84 0.70
0.0 1.18 0.84 0.70
0.0 1.18 0.84 0.70
V_9= 2.75


T^R
s_0^R
s_1^R
s_2^R
0.0
0.89
0.68
T^A
T^A
T^A
s_0^A s_1^A s_2^A s_3^A
s_0^A s_1^A s_2^A s_3^A
s_0^A s_1^A s_2^A s_3^A
0.0 1.18 0.84 0.70
0.0 1.18 0.84 0.70
0.0 1.18 0.84 0.70
V_{10}= 3.59


T^R
s_0^R
s_1^R
s_2^R
0.0
0.89
0.68
T^A
T^A
T^A
s_0^A s_1^A s_2^A s_3^A
s_0^A s_1^A s_2^A s_3^A
s_0^A s_1^A s_2^A s_3^A
0.0 1.18 0.84 0.70
0.0 1.18 0.84 0.70
0.0 1.18 0.84 0.70
V_{11}= 4.29

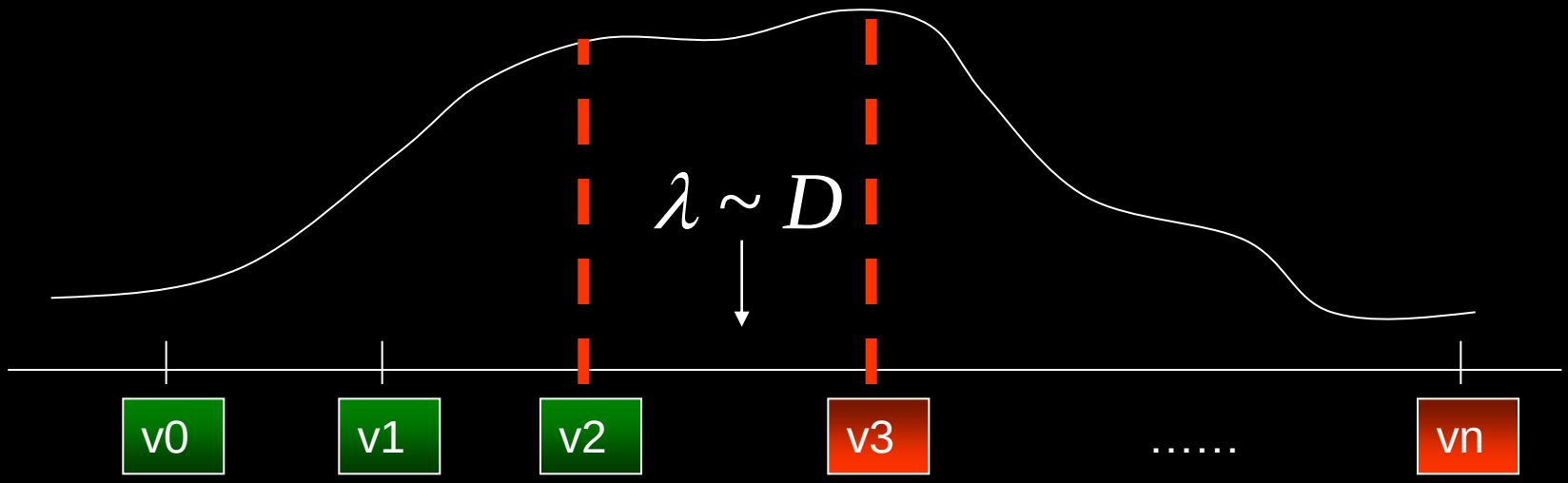

Conjunctive rule
3.61 < λ ≤ 4.29
T^R
S_0^R
S_1^R
S_2^R
0.0
0.89
0.68
T^A
T^A
T^A
S_0^A S_1^A S_2^A S_3^A
S_0^A S_1^A S_2^A S_3^A
S_0^A S_1^A S_2^A S_3^A
0.74
0.74
0.74
V_0= 0
V_1= 1.18
V_2= 2.02
V_3= 2.72
V_4= 0.89
V_5= 2.07
V_6= 2.91
V_7= 3.61
V_8= 1.57
V_9= 2.75
V_{10}= 3.59
V_{11}= 4.29


Disjunctive rule
0.00 < λ ≤ 0.89
T^R
s_0^R
s_1^R
s_2^R
0.0
0.89
0.68
T^A
T^A
T^A
s_0^A s_1^A s_2^A s_3^A
s_0^A s_1^A s_2^A s_3^A
s_0^A s_1^A s_2^A s_3^A
0.0
0.0
0.0
V_0= 0
V_1= 1.18
V_2= 2.02
V_3= 2.72
V_4= 0.89
V_5= 2.07
V_6= 2.91
V_7= 3.61
V_8= 1.57
V_9= 2.75
V_{10}= 3.59
V_{11}= 4.29


Lexicographic rule
1.57 < λ ≤ 2.02
T^R
s_0^R
s_1^R
s_2^R
0.0
0.89
0.68
T^A
T^A
T^A
s_0^A s_1^A s_2^A s_3^A
s_0^A s_1^A s_2^A s_3^A
s_0^A s_1^A s_2^A s_3^A
0.0 1.18
0.0 1.18
0.0 1.18
V1= 1.18
V2= 2.02
V3= 2.72
V5= 2.07
V6= 2.91
V7= 3.61
V9= 2.75
V10= 3.59
V11= 4.29

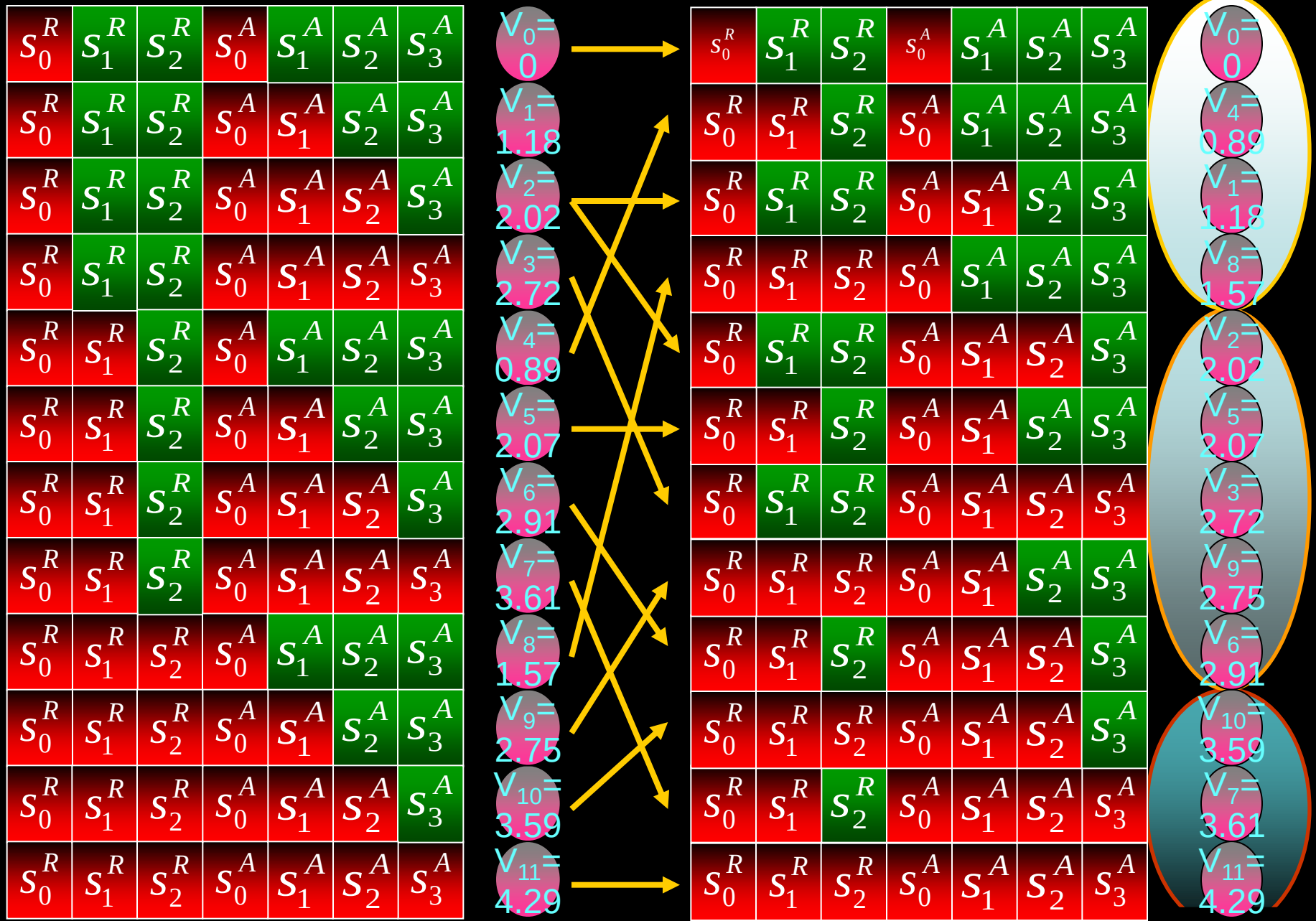
$$v_n + \varepsilon \geq \lambda \Leftrightarrow v_n \geq \lambda \sim D$$

Stochastic contextual factor



The probability of a preference is equivalent to the probability of λ being in the invariant range.

$$p_{k+1} = \int_{v_k}^{v_{k+1}} D \times dt$$

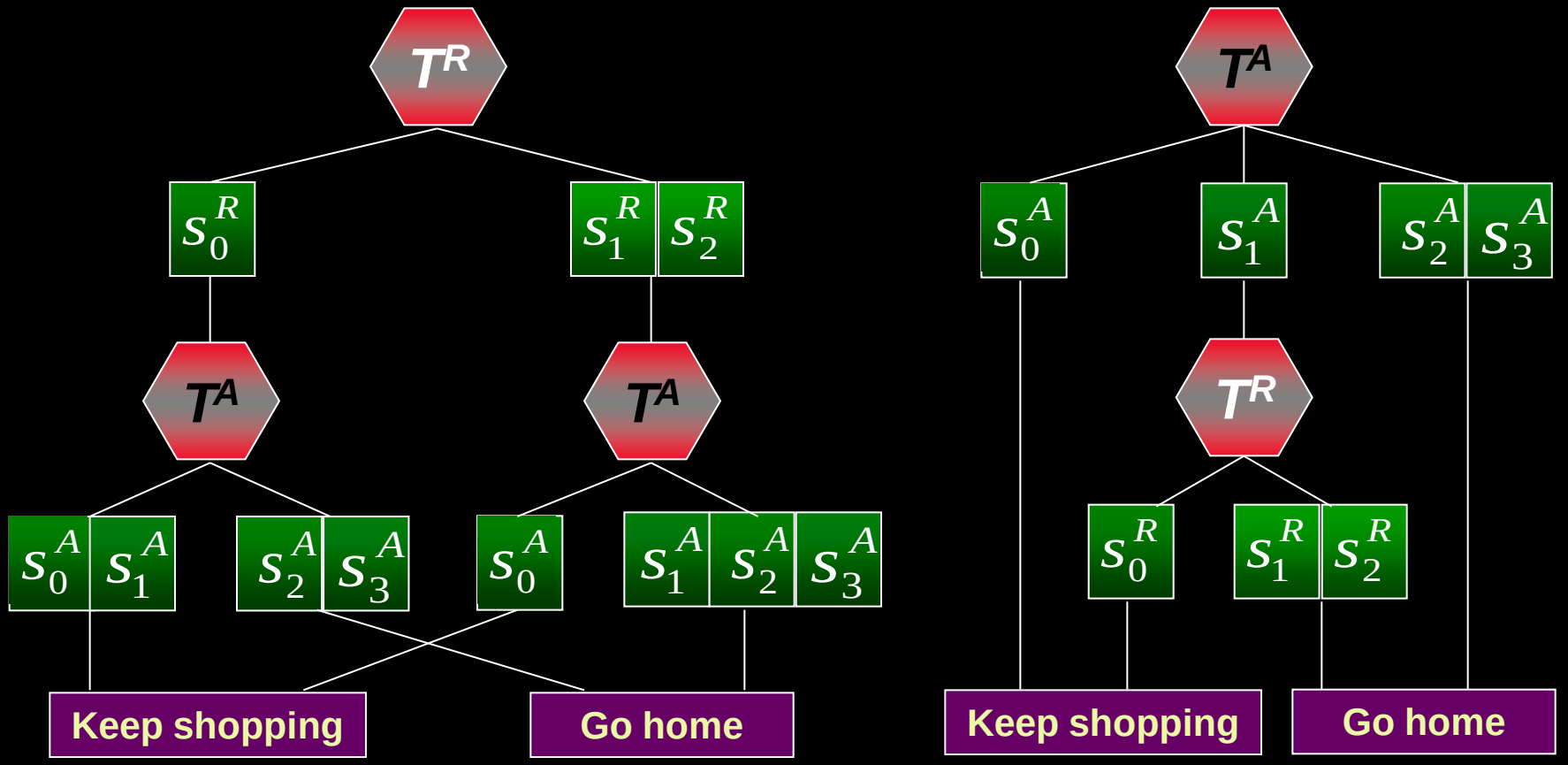

S_0^R S_1^R S_2^R S_0^A S_1^A S_2^A S_3^A
V_0= 0
V_1= 1.18
V_2= 2.02
V_3= 2.72
V_4= 0.89
V_5= 2.07
V_6= 2.91
V_7= 3.61
V_8= 1.57
V_9= 2.75
V_{10}= 3.59
V_{11}= 4.29
V_0= 0
V_4= 0.89
V_1= 1.18
V_8= 1.57
V_2= 2.02
V_5= 2.07
V_3= 2.72
V_9= 2.75
V_6= 2.91
V_{10}= 3.59
V_7= 3.61
V_{11}= 4.29
PREFERENCE TOLRERANCE

Mental effort

Lexicographic rule

$1.57 < \lambda \leq 2.02$

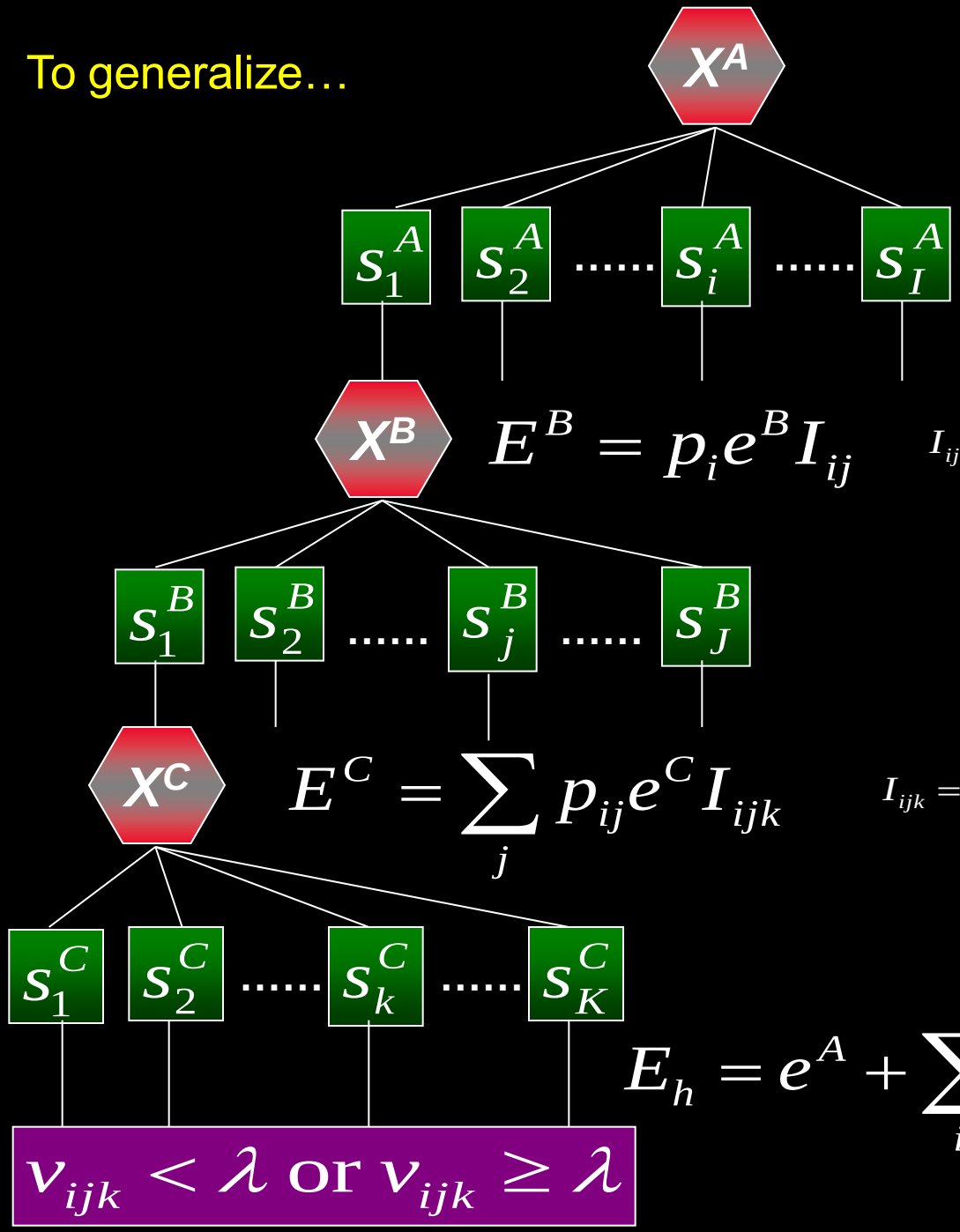
Homogeneous responses do not necessitate further search



$$E_h^{RA} = e^R + (p_0^R + p_1^R + p_2^R) \times e^A = e^R + e^A$$

$$E_h^{AR} = e^A + p_1^A \times e^R$$

To generalize…

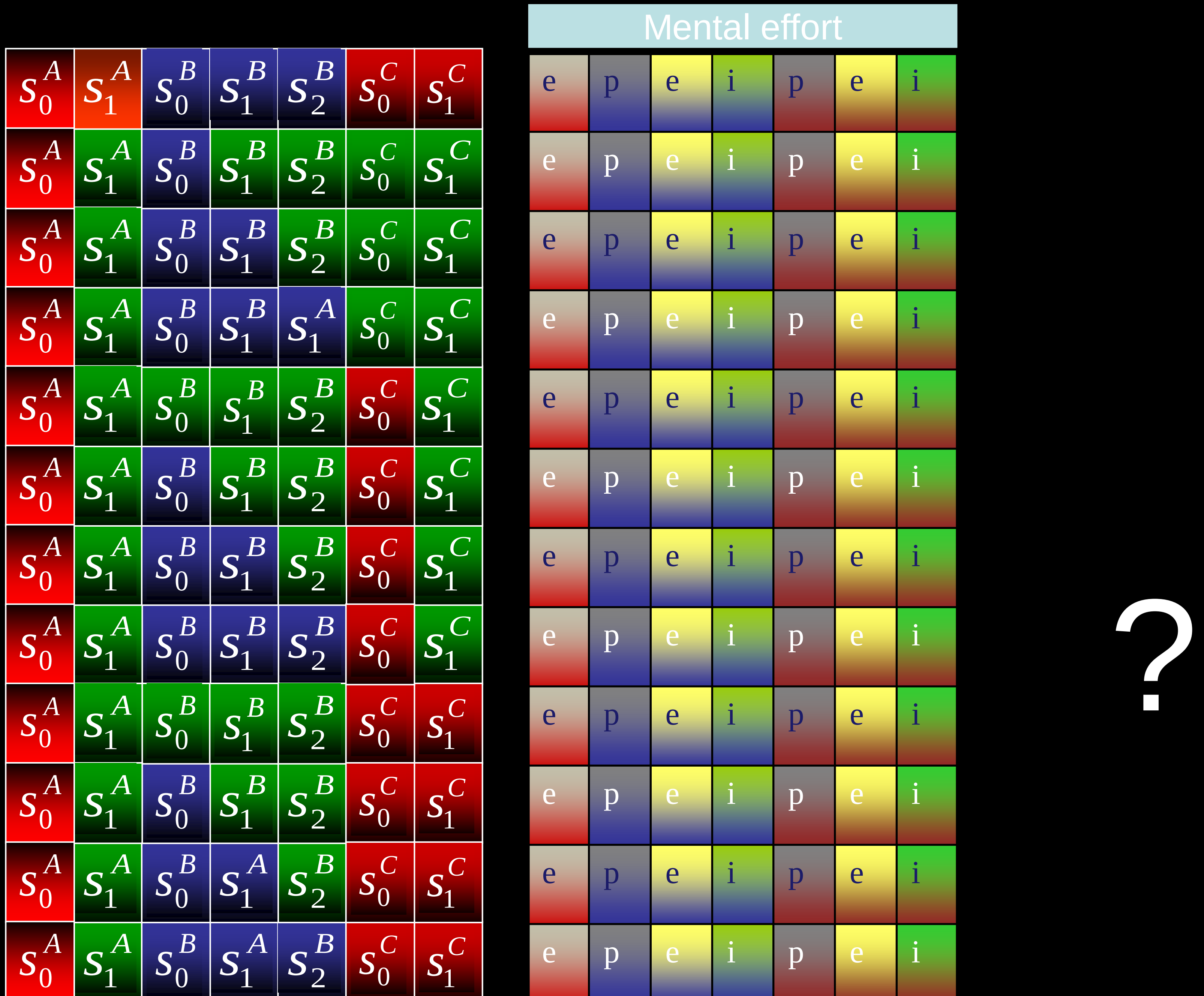


$$e^A + \sum_i E^B + E^C$$

$$E^B = p_i e^B I_{ij} \qquad I_{ij} = \begin{cases} 0, \text{ if all } v_{ijk} \mid i \text{ are rejected or accepted} \\ 1, \text{ otherwise} \end{cases}$$

$$E^C = \sum_j p_{ij} e^C I_{ijk} \qquad I_{ijk} = \begin{cases} 0, \text{ if all } v_{ijk} \mid i, j \text{ are rejected or accepted} \\ 1, \text{ otherwise} \end{cases}$$

$$E_h = e^A + \sum_i p_i e^B I_{ij} + \sum_j p_{ij} e^C I_{ijk}$$


S_0^A S_1^A S_0^B S_1^B S_2^B S_0^C S_1^C
S_0^A S_1^A S_0^B S_1^B S_2^B S_0^C S_1^C
S_0^A S_1^A S_0^B S_1^B S_2^B S_0^C S_1^C
S_0^A S_1^A S_0^B S_1^B S_1^A S_0^C S_1^C
S_0^A S_1^A S_0^B S_1^B S_2^B S_0^C S_1^C
S_0^A S_1^A S_0^B S_1^B S_2^B S_0^C S_1^C
S_0^A S_1^A S_0^B S_1^B S_2^B S_0^C S_1^C
S_0^A S_1^A S_0^B S_1^B S_2^B S_0^C S_1^C
S_0^A S_1^A S_0^B S_1^B S_2^B S_0^C S_1^C
S_0^A S_1^A S_0^B S_1^B S_2^B S_0^C S_1^C
S_0^A S_1^A S_0^B S_1^A S_2^B S_0^C S_1^C
S_0^A S_1^A S_0^B S_1^A S_2^B S_0^C S_1^C
Mental effort
e p e i p e i
e p e i p e i
e p e i p e i
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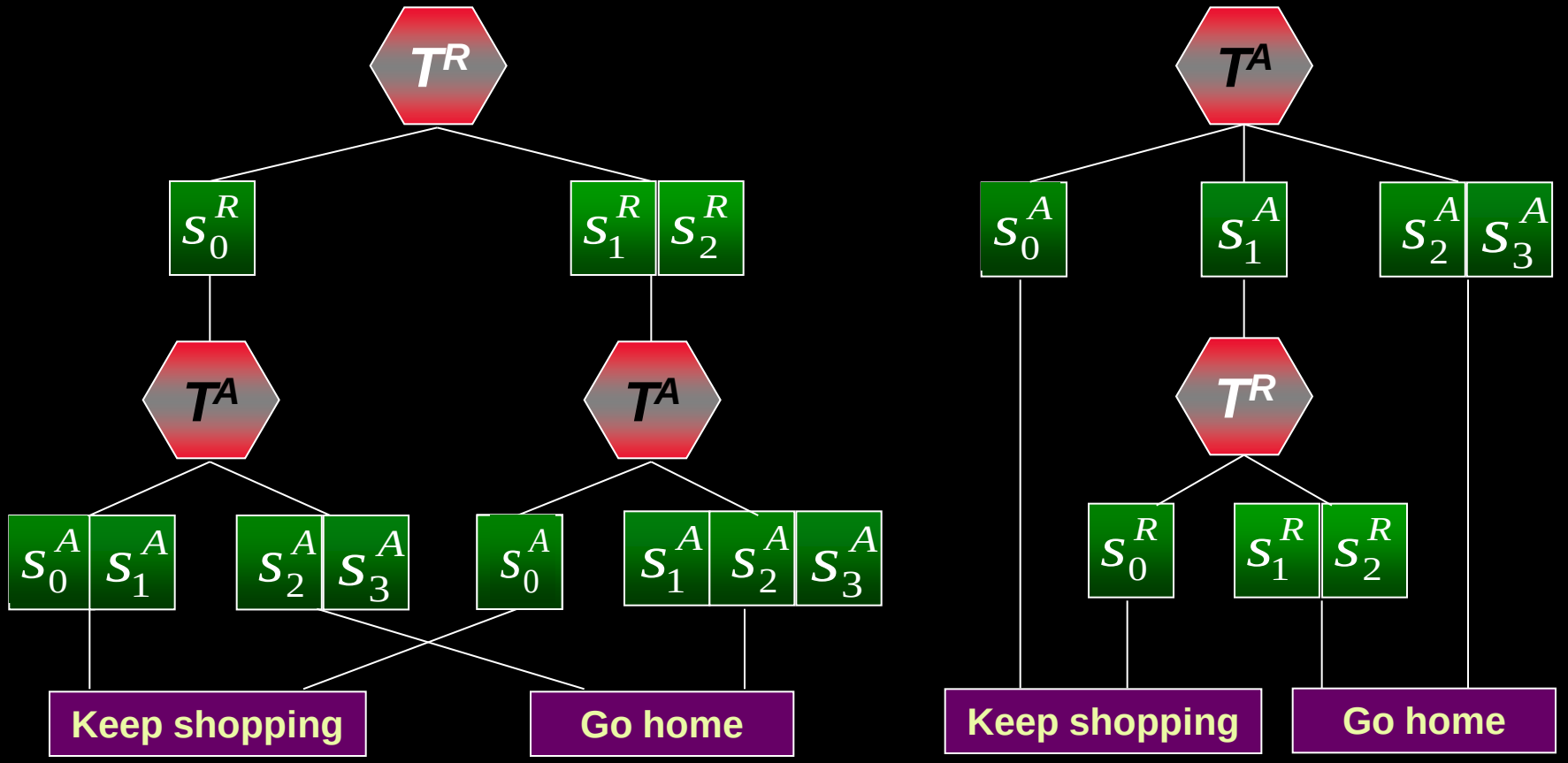
e p e i p e i
?

Risk attitude

$$R_h = -R_h^+ \log_2(R_h^+) - R_h^- \log_2(R_h^-)$$

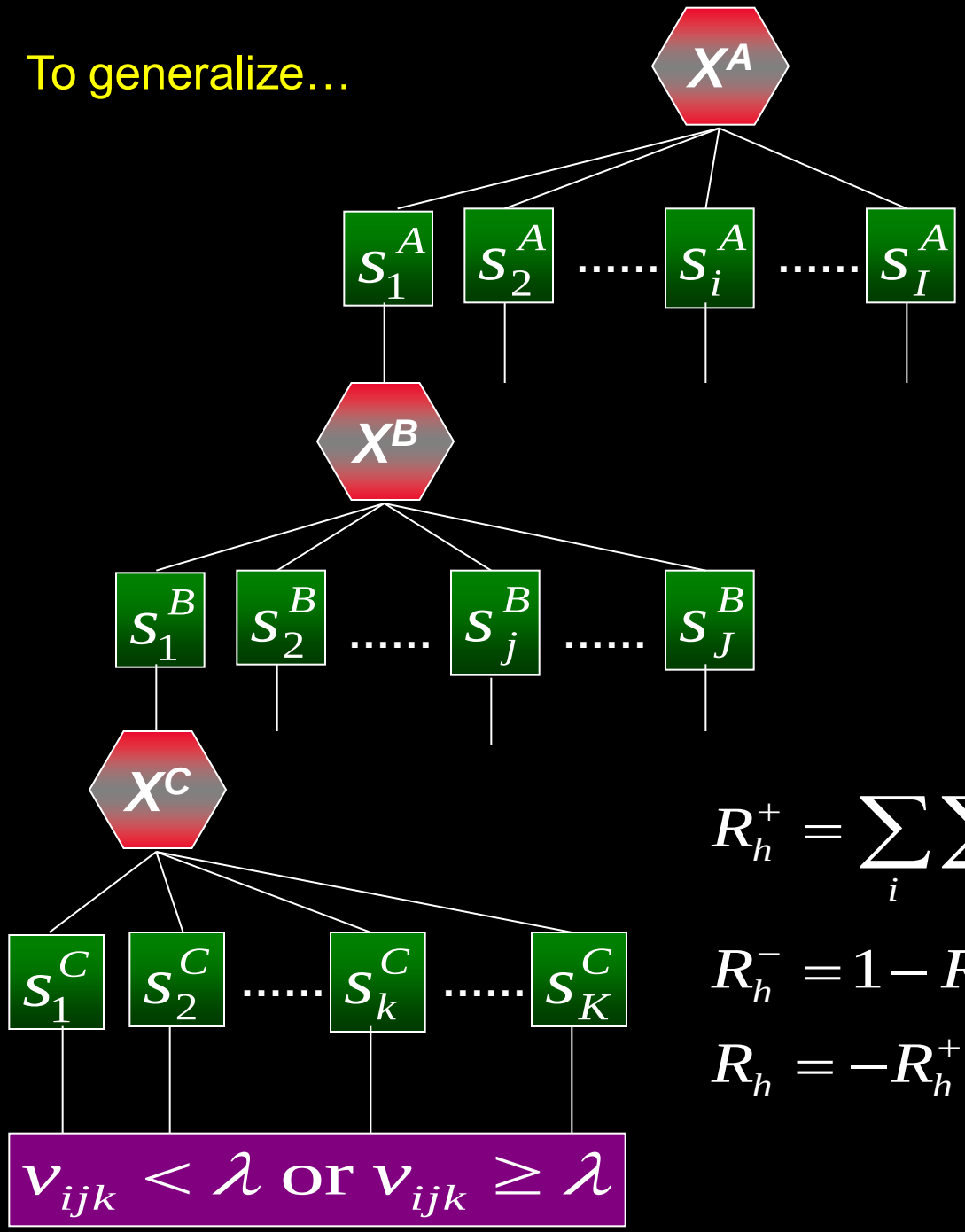
Shannon's Information Entropy as a measure of heuristic uncertainty



$$R_h^+ = p_0^R(p_2^A + p_3^A) + (p_1^R + p_2^R)(p_1^A + p_2^A + p_3^A) = p_1^A(p_1^R + p_2^R) + p_2^A + p_3^A$$

$$R_h^- = 1 - R_h^+$$

To generalize…



$$R_h^+ = \sum_i \sum_j \sum_k p_{ijk} \mid v_{ijk} \geq \lambda$$

$$R_h^- = 1 - R_h^+$$

$$R_h = -R_h^+ \log_2(R_h^+) - R_h^- \log_2(R_h^-)$$

s_0^A	s_1^A	s_0^B	s_1^B	s_2^B	s_0^C	s_1^C
s_0^A	s_1^A	s_0^B	s_1^B	s_2^B	s_0^C	s_1^C
s_0^A	s_1^A	s_0^B	s_1^B	s_2^B	s_0^C	s_1^C
s_0^A	s_1^A	s_0^B	s_1^B	s_1^A	s_0^C	s_1^C
s_0^A	s_1^A	s_0^B	s_1^B	s_2^B	s_0^C	s_1^C
s_0^A	s_1^A	s_0^B	s_1^B	s_2^B	s_0^C	s_1^C
s_0^A	s_1^A	s_0^B	s_1^B	s_2^B	s_0^C	s_1^C
s_0^A	s_1^A	s_0^B	s_1^B	s_2^B	s_0^C	s_1^C
s_0^A	s_1^A	s_0^B	s_1^B	s_2^B	s_0^C	s_1^C
s_0^A	s_1^A	s_0^B	s_1^B	s_2^B	s_0^C	s_1^C
s_0^A	s_1^A	s_0^B	s_1^A	s_2^B	s_0^C	s_1^C
s_0^A	s_1^A	s_0^B	s_1^A	s_2^B	s_0^C	s_1^C

Risk

e	p	e	i	p	e	i
e	p	e	i	p	e	i
e	p	e	i	p	e	i
e	p	e	i	p	e	i
e	p	e	i	p	e	i
e	p	e	i	p	e	i
e	p	e	i	p	e	i
e	p	e	i	p	e	i
e	p	e	i	p	e	i
e	p	e	i	p	e	i
e	p	e	i	p	e	i
e	p	e	i	p	e	i

?

Utility of heuristic

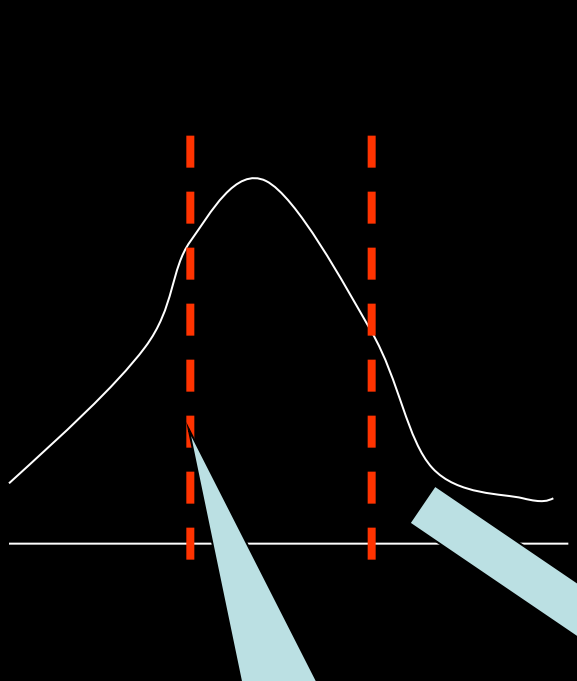
$$U_h = \beta_E E_h + \beta_R R_h$$

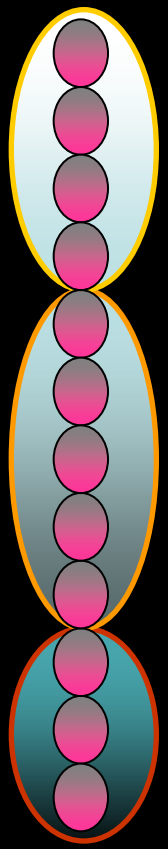
Choice of heuristic

Step1: Discretize context

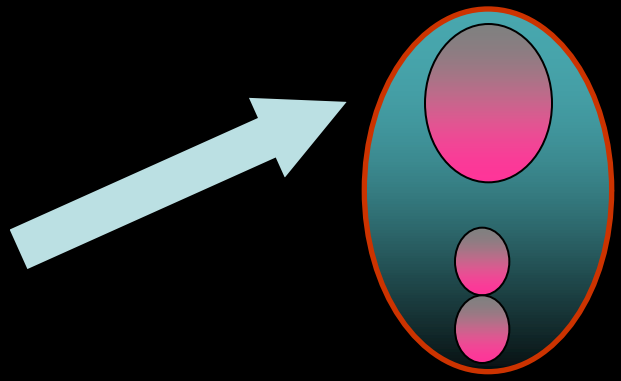
Step2: Identify preference group

Step3: Choose heuristic



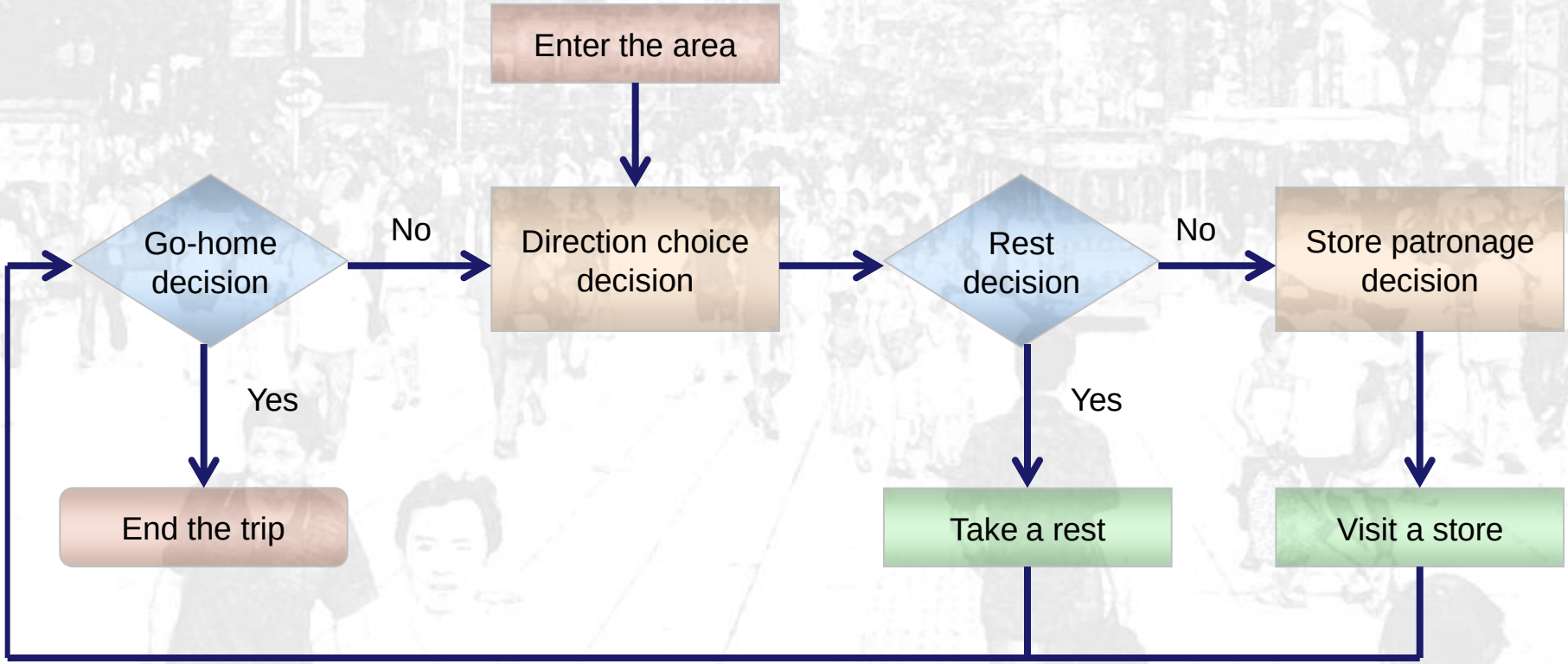


$$p_{h \in z_g} = p_{z_g} \frac{\exp(U_h)}{\sum_{h' \in z_g} \exp(U_{h'})}$$



Conceptual Framework

- Decisions to model
  - Go home, direction choice, rest, store patronage



Conceptual Framework

- Three model prototypes for comparison

MNL

- As the representative of rational choice models and a benchmark

PH

- Heuristic models with probabilistic threshold specifications

HHM

- The Heterogeneous Heuristic Model, which is the major methodological contribution of the thesis

Problem Representation

- Concepts
  - Attribute
  - Attribute threshold
  - Attribute state
  - State utility
  - Overall utility

$$X = \{x_j \mid j = 1, \ldots, J\}$$

$$\Delta_j = \{\delta_{j1} < \delta_{jn} < \delta_{jN}\}$$

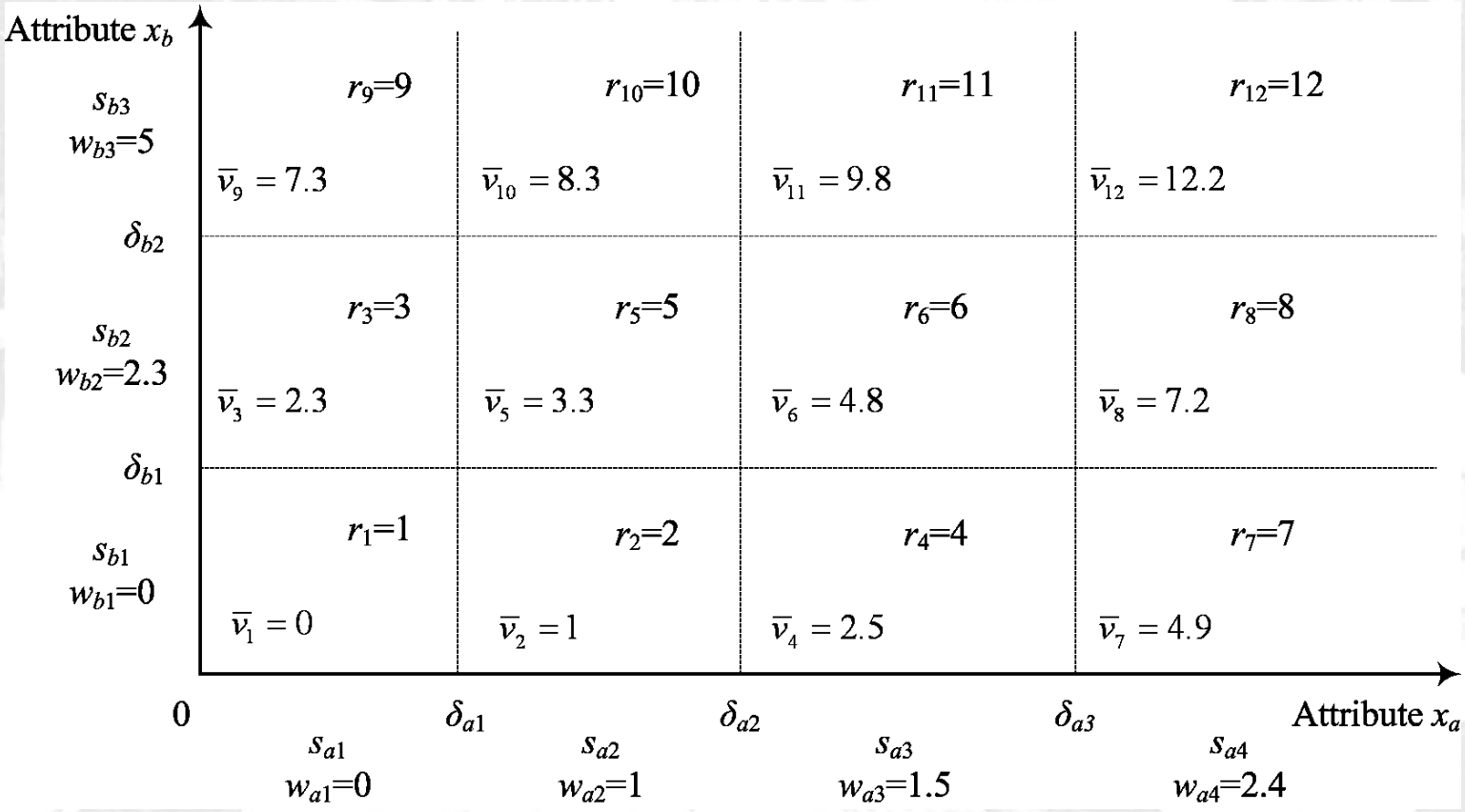
$$s_{jn} = \begin{cases} 0 & \text{if } x_j < \delta_{jn} \\ 1 & \text{if } x_j \geq \delta_{jn} \end{cases}$$

$$u_{jn} = w_{jn} s_{jn}$$

$$v_i = \sum_j \sum_n u_{ijn}$$

An Example

- Two-attribute representation



Satisficing Decision

- A preference is a function of
  - Alternative rank
  - Reference rank
  - Decision criterion (discriminant threshold)

r_i

r_ε

λ_k

$$d_i = \begin{cases} 1 & \text{if } r_i - r_\varepsilon \geq \lambda_k \quad \lambda_k \in [1, K] \\ 0 & \text{if } r_i - r_\varepsilon \leq -\lambda_k \\ 0.5 & \text{otherwise} \end{cases}$$

Behavioral Heterogeneity

- We focus on the variation of decision criteria, because it is more common and easier to change criteria than representation.
- Using a latent class structure
- A decision criterion is selected based on its value

$$d_i = \sum_{k=1}^{K} p_k d_{i|k}$$

$$p_k = \frac{\exp(u_k)}{\sum_{k'=1}^{K} \exp(u_{k'})}$$

Factors of Criterion Value

- Consistency
  - Preference based on the criterion
  - Preferences based on other criteria
  - To what extent they are consistent?
  - So that current choice is also robust in the future

Value of having consistent preferences

$$\psi_{l|k} = \sum_{k'=1}^{K} \eta_{k'} \mathrm{I}(d_{l|k'} = d_{l|k})$$

$$\eta_{k'|k} = \exp(\beta_{\psi} \mid k' - k \mid)$$

Positive: expecting different future preferences
Negative: expecting similar future preferences

Probability belief of attribute state

$$p_l = \prod_j p_{jn}$$

Probability of overall state

$$\psi_k = \sum_l p_l \psi_{l|k}$$

Factors of Criterion Value

- Definiteness
  - The probability of getting a definite result (clear discrimination between alternatives)

$$\gamma_k = \sum_l p_l \gamma_{l|k}$$

$$\gamma_{l|k} = \mathrm{I}(d_{l|k} \neq 0.5)$$

- In total

$$u_k = \psi_k + \beta_\gamma \gamma_k$$

What to Estimate?

- Attribute thresholds $\Delta_j = \{\delta_{j1}, \ldots \delta_{jN}\}$
- Attribute utilities $W_j = \{w_{j1} = 0, w_{j2}, \ldots, w_{jN+1}\}$
- Reference rank r_ε
- Parameters in criterion choice β_ψ, β_γ

Technical problems in estimation
(1)Thresholds are non-continuous; numbers are estimated
(2)Attribute utilities are non-unique
(3)Conventional significance tests do not apply; using CAIC instead

Illustration

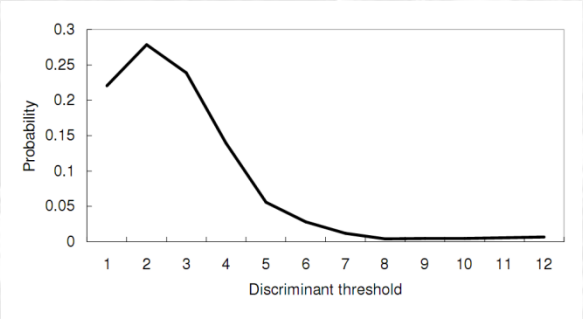
- Go-home decision: pedestrians' decision to end a shopping trip
- Three datasets of pedestrian shopping diary
  - East Nanjing Road, Shanghai (2003, 2007)
  - Wang Fujing Street, Beijing (2004)
- Attributes
  - Relative time (t^R), absolute time (t^A)

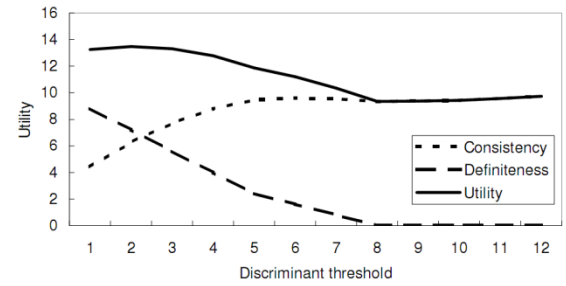
Parameter Estimates

Parameter	ENR-03 Estimate	WFS-04 Estimate	ENR-07 Estimate
δ_1^R	180 minutes	90 minutes	70 minutes
δ_2^R	480 minutes	180 minutes	240 minutes
$[w_1^R]$	1	1	1
w_2^R	0.720	0.561	0.104
δ_1^A	14:30	14:00	14:30
δ_2^A	17:00	16:00	19:30
δ_3^A	20:00	19:00	-
w_1^A	5.860	7.143	0.504
w_2^A	0.274	0.664	1.019
w_3^A	0.734	0.337	-
r_ε	8	10	7
β_ψ	0.023	-0.253	0.188
β_γ	9.610	6.822	6.410

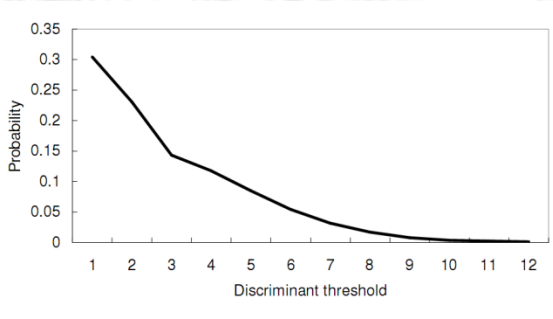
Use of Criteria

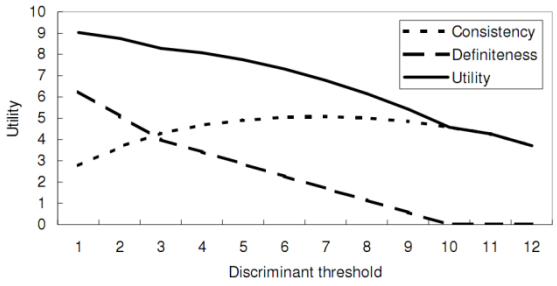
ENR-03



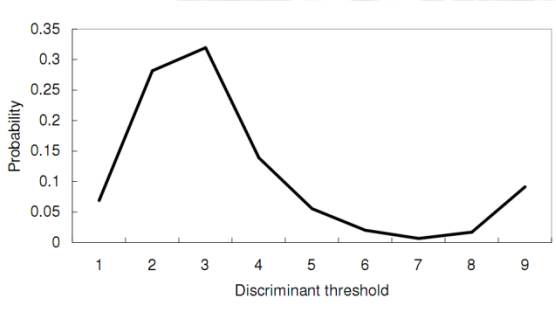


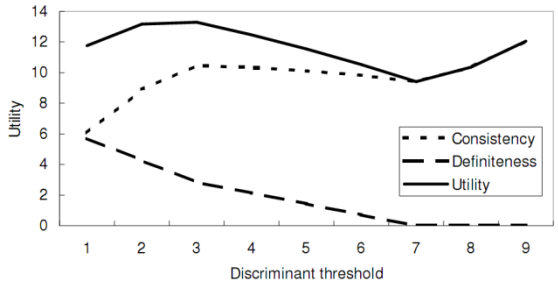
WFS-04





ENR-07





Goodness-of-fits

Parameter	ENR-03			WFS-04			ENR-07		
	Proposed	MNL	Mixed	Proposed	MNL	Mixed	Proposed	MNL	Mixed
LL	-730	-789	-788	-1037	-1085	-1079	-402	-410	-409
N_C	1926	1926	1926	2741	2741	2741	808	808	808
N_P	12	3	6	12	3	6	10	3	6
CAIC	1562	1603	1628	2181	2197	2211	880	843	866

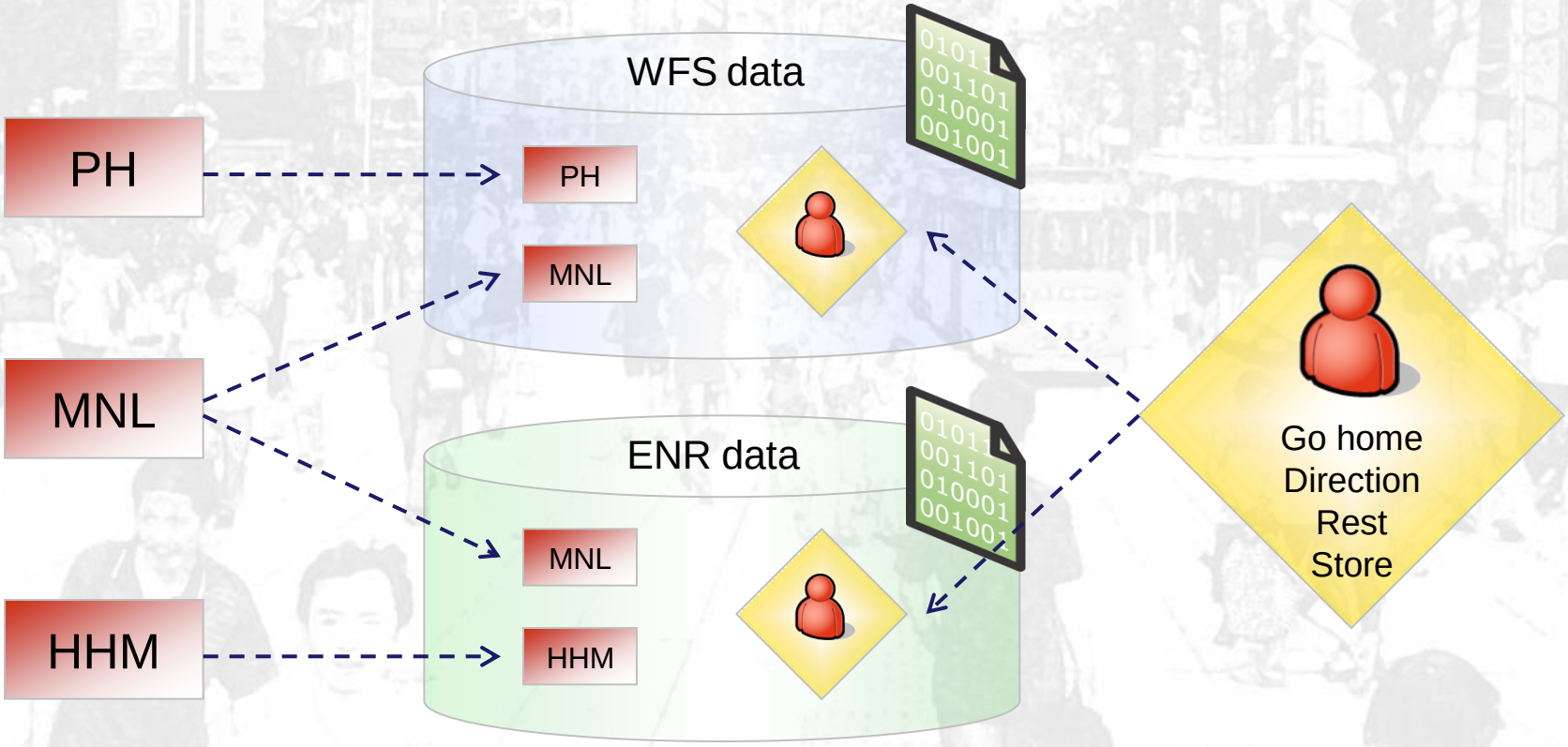
LL: log-likelihood
N_C: number of cases
N_P: number of parameters
CAIC: Consistent Akaike Information Criterion

Conclusion

- Theoretical
  - Model behavioral heterogeneity by explicitly taking into account the variation of decision criteria
  - Choice of criteria explained by consistency and definiteness
- Empirical
  - Definiteness is the dominant factor; pedestrians prefer using relaxed criteria
  - Consistency is less influential; pedestrians' expectations on future preferences are diverse
  - Better capture heterogeneity for large samples

Model Estimation

- Each of the three prototype models is specified for each of the four decisions and estimated against data.



Model Estimation

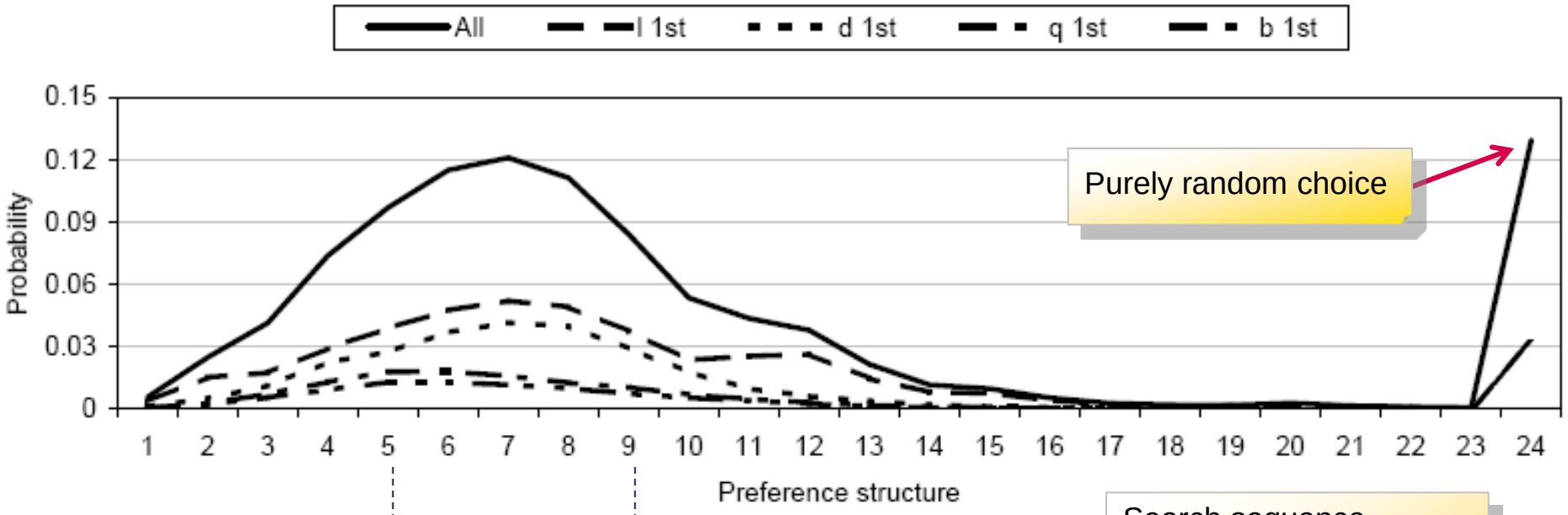
- Models are compared in terms of Log-likelihood statistics and Consistent Akaike Information Criterion.

- In general, heuristic models are better than MNL models, suggesting pedestrians using simplifying decision strategies.

Decision	WFS		ENR	
	Best LL	Best CAIC	Best LL	Best CAIC
Go-home	LEX	CONJ	HHM	MNL logged
Direction choice	LEX	LEX	HHM	HHM
Rest	CONJ	LEX	HHM	MNL logged
Store patronage	LEX	LEX	HHM	HHM

Model Estimation

- The major advantage of HHM is to estimate the probabilistic use of heuristics.



Conclusion

1

BR model

- The advantage of using BR models to modeling pedestrian decision processes is partially justified, suggesting a promising new line of behavior / decision modeling.

2

Heterogeneity

- HHM provides a potential framework for modeling the formation and choice of heuristics, which may contribute to decision research at large.

3

Time

- Including temporal factors is valuable for capturing dynamic pedestrian behavior. However, temporal change in behavior was not estimated.

MODEL OF MENTAL REPRESENTATION AND ACTIVATION

Assumptions

Individuals construct and activite a mental model

This representation involves causal mechanisms, linking decision problem and situational variables to outcomes

It involve a subjective representation of the environment and beliefs

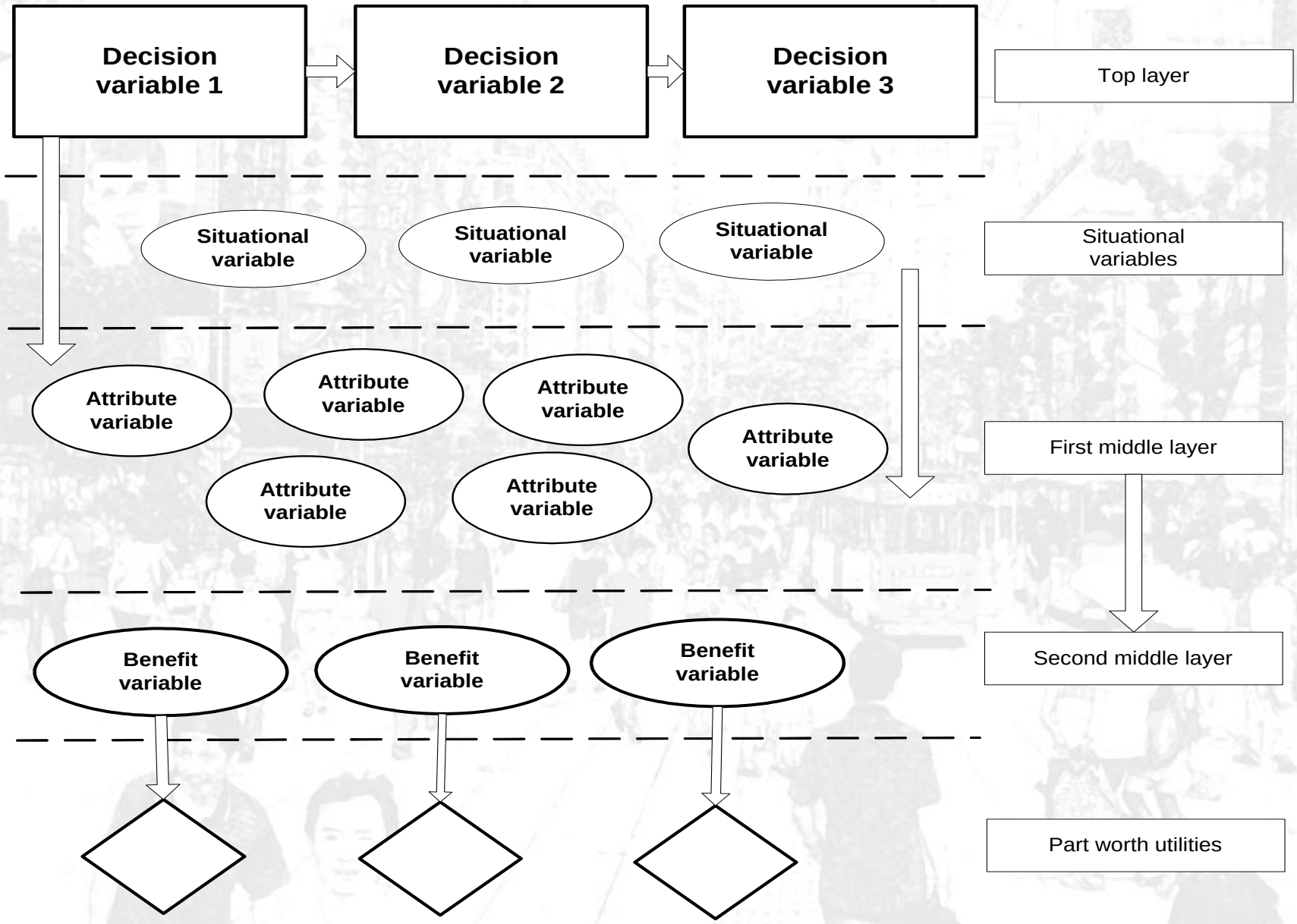
It involves an assessment of size of benefits

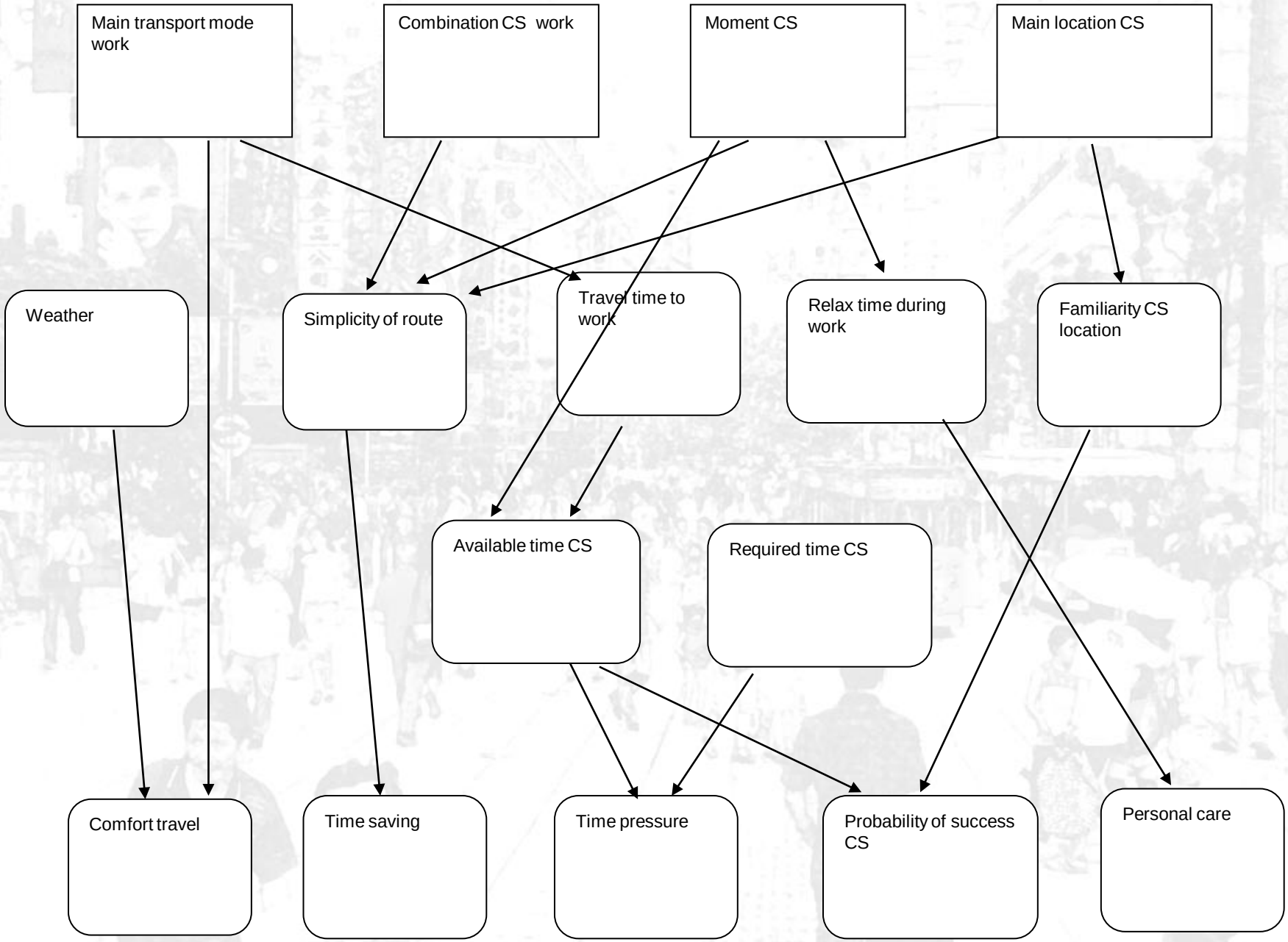
Theory

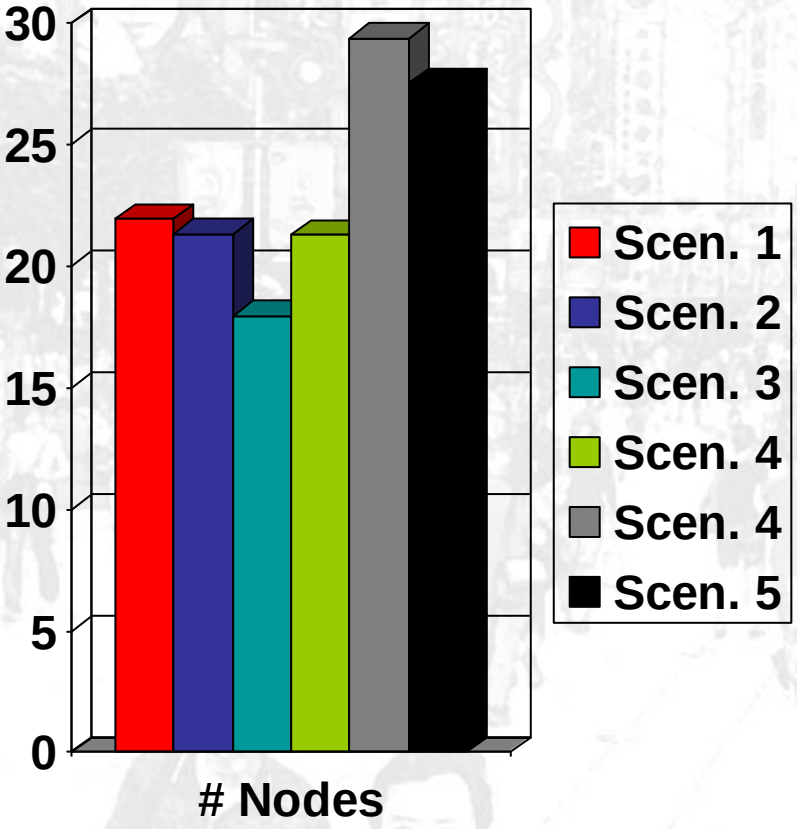
Mental model is a temporary and active cognitive structure, tailored to the specific settings of the task

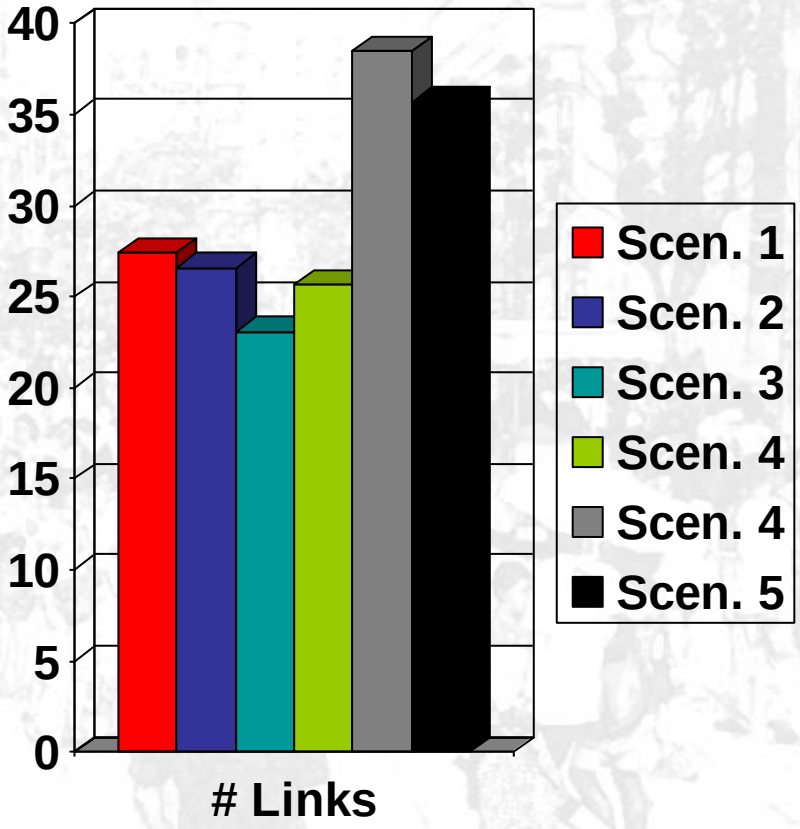
It serves to reduce the complexity of the decision task

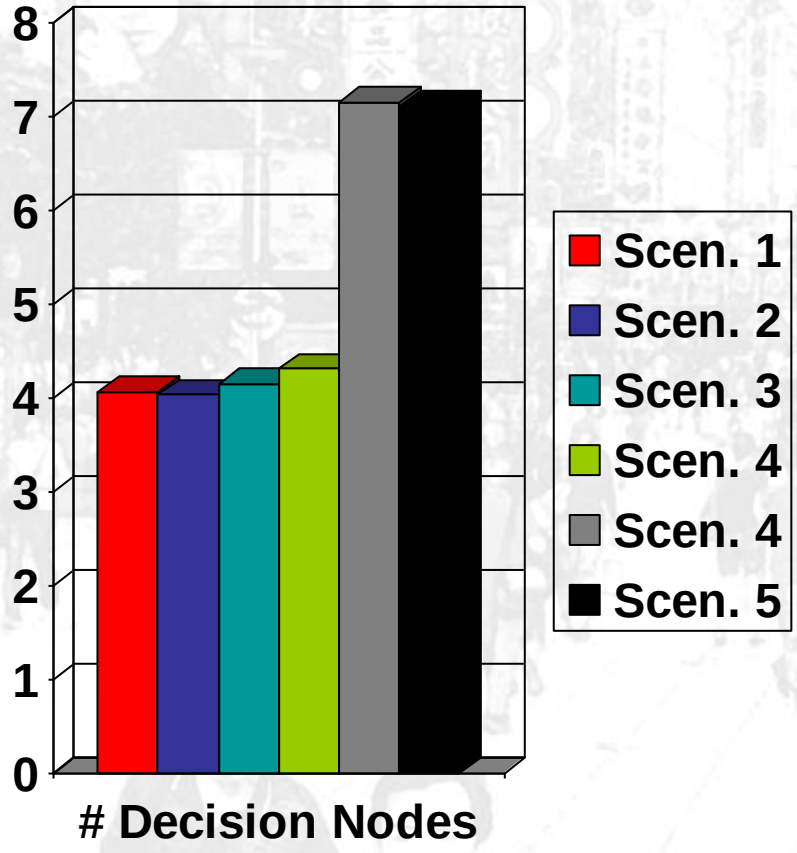
It allows individual to solve the problem within the boundaries of his rationality

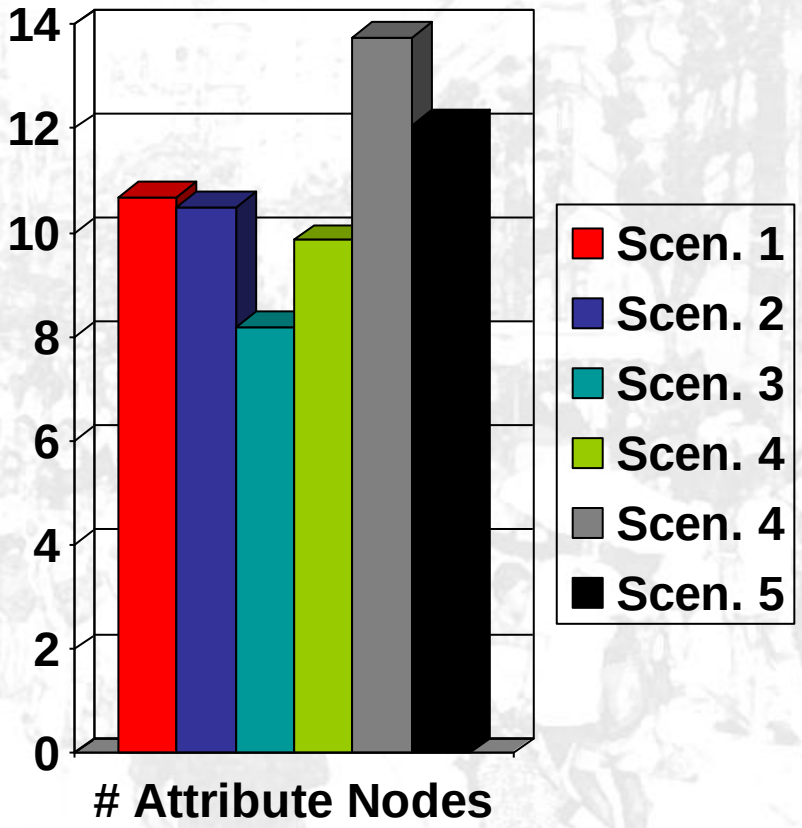

Decision variable 1
Decision variable 2
Decision variable 3
Top layer
Situational variable
Situational variable
Situational variable
Situational variables
Attribute variable
Attribute variable
Attribute variable
Attribute variable
Attribute variable
Attribute variable
First middle layer
Benefit variable
Benefit variable
Benefit variable
Second middle layer
Part worth utilities

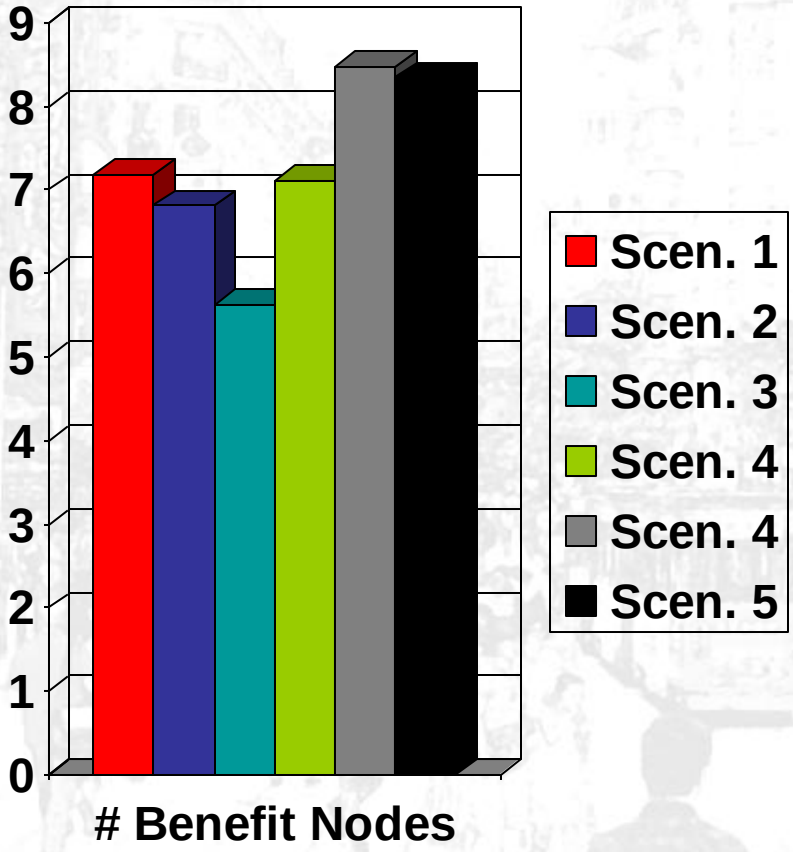

Main transport mode work
Combination CS work
Moment CS
Main location CS
Weather
Simplicity of route
Travel time to work
Relax time during work
Familiarity CS location
Available time CS
Required time CS
Comfort travel
Time saving
Time pressure
Probability of success CS
Personal care


30
25
20
15
10
5
0
Scen. 1
Scen. 2
Scen. 3
Scen. 4
Scen. 4
Scen. 5
Nodes


40
35
30
25
20
15
10
5
0
Scen. 1
Scen. 2
Scen. 3
Scen. 4
Scen. 4
Scen. 5
Links


8
7
6
5
4
3
2
1
0
Scen. 1
Scen. 2
Scen. 3
Scen. 4
Scen. 4
Scen. 5
Decision Nodes


14
12
10
8
6
4
2
0
Scen. 1
Scen. 2
Scen. 3
Scen. 4
Scen. 4
Scen. 5
Attribute Nodes


9
8
7
6
5
4
3
2
1
0
Benefit Nodes
Scen. 1
Scen. 2
Scen. 3
Scen. 4
Scen. 4
Scen. 5

Dependent variable	Grouping variable	F	Sig,
Number of nodes (total)	Scenario	37,263	0,000
	Interviewer	7,371	0,001
	Scenario x interviewer	0,883	0,883
Number of links	Scenario	35,572	0,000
	Interviewer	5,613	0,004
	Scenario x interviewer	0,452	0,918
Decision nodes	Scenario	322,904	0,000
	Interviewer	0,586	0,558
	Scenario x interviewer	0,846	0,585
Number of attribute nodes	Scenario	15,431	0,000
	Interviewer	2,189	0,115
	Scenario x interviewer	0,825	0,606
Number of benefit nodes	Scenario	11,319	0,000
	Interviewer	15,596	0,000
	Scenario x interviewer	0,653	0,766

Model

$$r_{ij}(x_{jkg}) = \beta_{kg}^{ij}$$

where

x_{jkg} is an (expected) outcome of alternative *g* of decision variable *k* on attribute *j*.

r_{ij} is an evaluation of the extent to which this outcome matches the most desired outcome given the need associated with benefit *i*.

β_{kg}^{ij} is a corresponding systematic utility value.

Model

A perceived gain of a DAB chain evaluation is defined as the size of utility difference it reveals compared to the case where the chain is not inspected

$$Z_{ijk} = SD(\beta_{k\bullet}^{ij})$$

Utility values are based on expectations that the individual derives from broader knowledge about the world and his or her own needs. A key distinction in this knowledge structure must be made between knowledge about relevant attributes and benefit components and the causal network connecting these components and how they relate to alternatives and the individual's own needs

$$\alpha_i \cdot s_{ij}^1 \cdot s_{jk}^2 \cdot r_{ij}^{'}(x_{jkg}) = \beta_{kg}^{ij}$$

Model

$$SD\left[r_{ij}^{'}(x_{jk\bullet})\right] \equiv 1$$

$$Z_{ijk} = SD[\alpha_i \cdot s_{ij}^1 \cdot s_{jk}^2 \cdot r_{ij}^{'}(x_{jkg})]$$

$$= \alpha_i \cdot s_{ij}^1 \cdot s_{jk}^2 \cdot SD[r_{ij}^{'}(x_{jkg})]$$

$$= \alpha_i \cdot s_{ij}^1 \cdot s_{jk}^2$$

Model

Mental Costs

$$C_{ijk} = c_{ij} + c_{jk}$$

$$U_{ijk} = Z_{ijk} - C_{ijk}$$

$$P[(i,j,k) \in MR] = P(U_{ijk} > 0)$$

Hybrid Affective - Cognitive Model

ENVIRONMENT

Physical	Stationary attributes
Transportation system	Semi-stationary attributes
Institutional context	Non-stationary attributes (endogenous)

Uncertainty

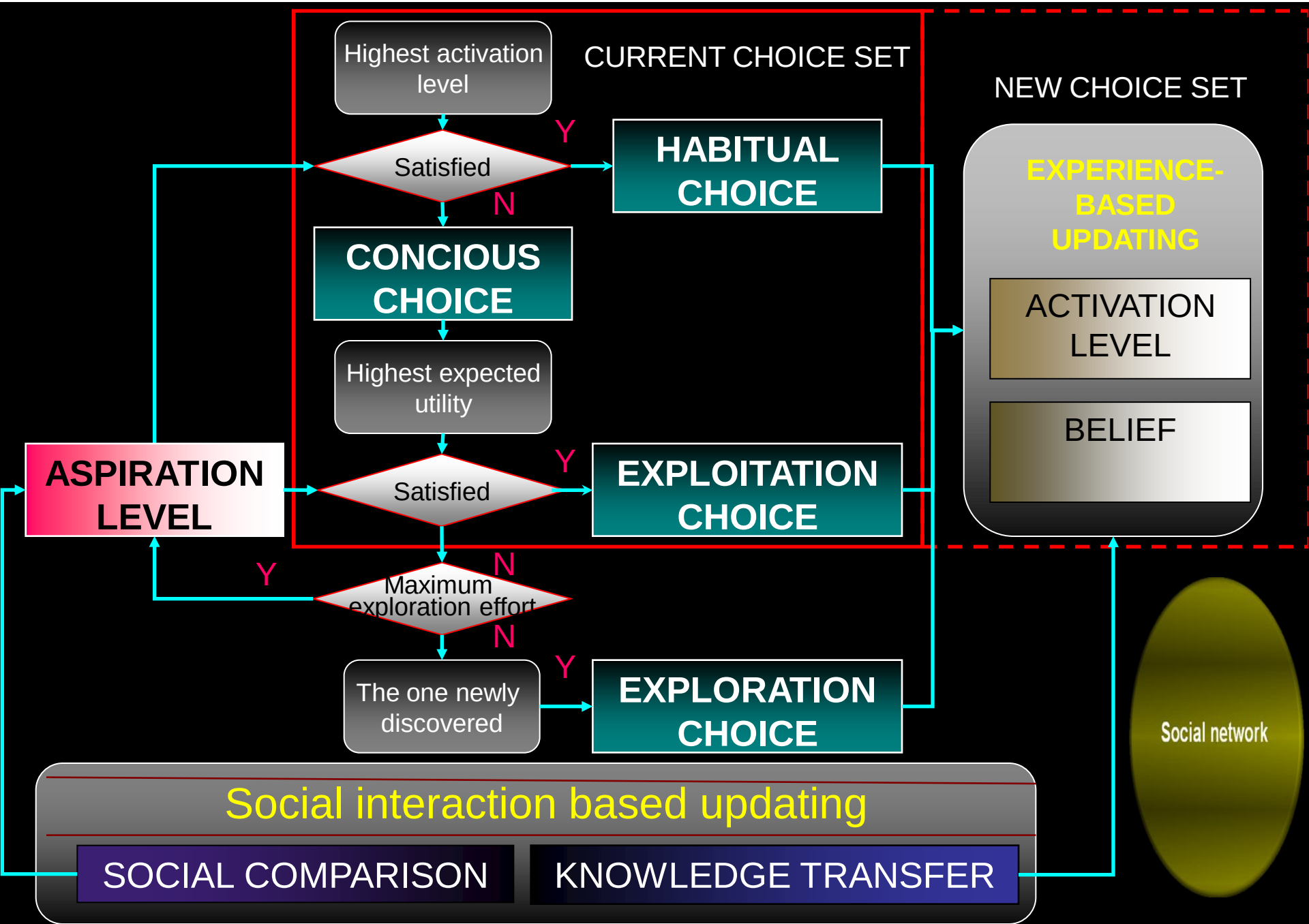
COGNITIVE ENVIRONMENT

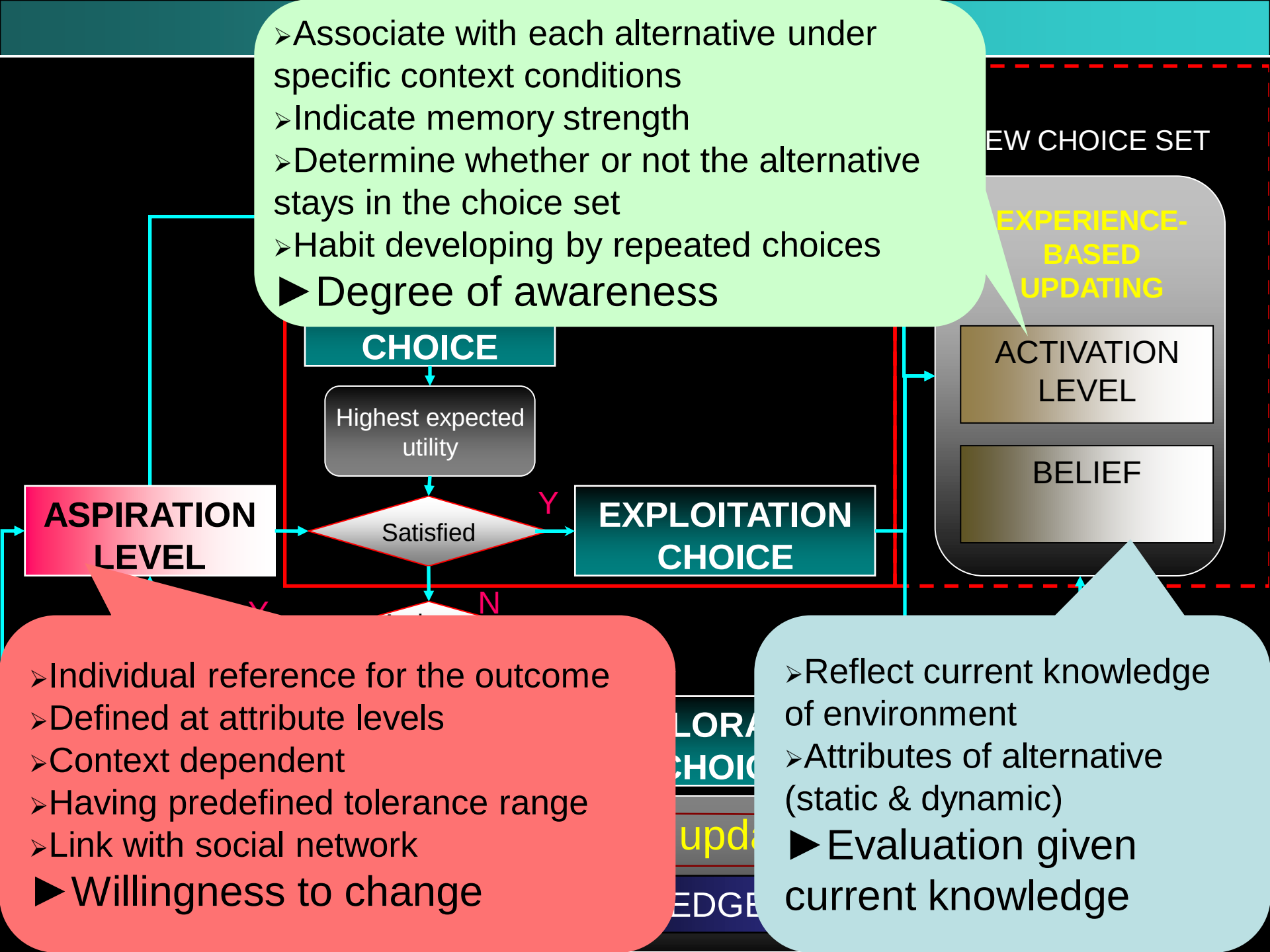
Context-dependent, time-varying	Beliefs, based on incomplete, imperfect perception
	Differential awareness

JUDGMENT and CHOICE

Context-dependent, time-varying	Aspiration level, mental effort and expected utility
	Constraints and resources
	Scripts, routines and heuristics

Process Model




➢Associate with each alternative under specific context conditions
➢Indicate memory strength
➢Determine whether or not the alternative stays in the choice set
➢Habit developing by repeated choices
►Degree of awareness
EW CHOICE SET
EXPERIENCE-BASED UPDATING
ACTIVATION LEVEL
BELIEF
CHOICE
Highest expected utility
Satisfied
Y
N
ASPIRATION LEVEL
EXPLOITATION CHOICE
➢Individual reference for the outcome
➢Defined at attribute levels
➢Context dependent
➢Having predefined tolerance range
➢Link with social network
►Willingness to change
➢Reflect current knowledge of environment
➢Attributes of alternative (static & dynamic)
►Evaluation given current knowledge

SOCIAL NETWORK

Ego

similarity
strength of link

Alter

EXCHANGE

KNOWLEDGE

alternatives

attributes

ASPIRATIONS

acceptance of information

social deviation tolerance

KNOWLEDGE

alternatives

attributes

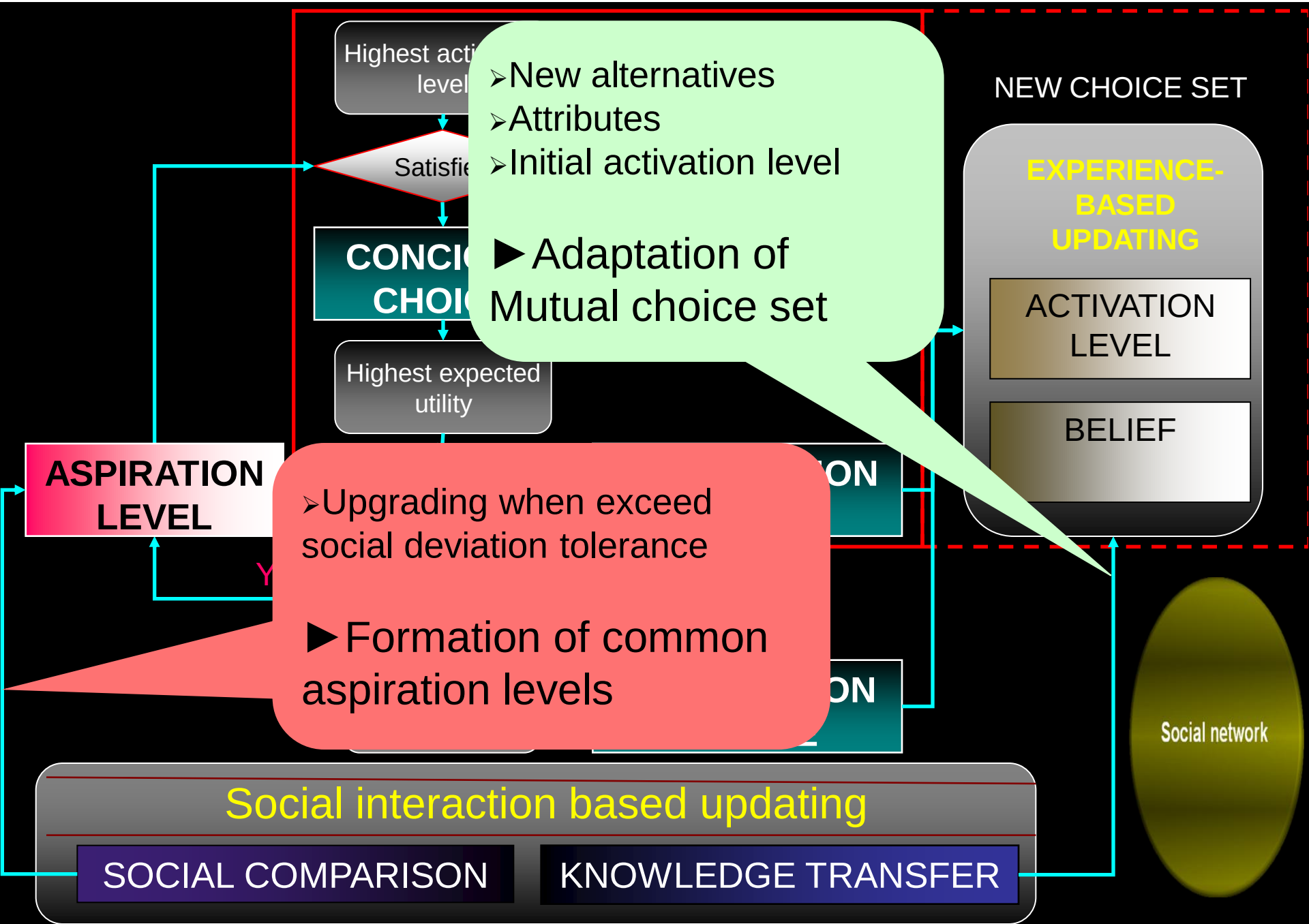
ASPIRATIONS

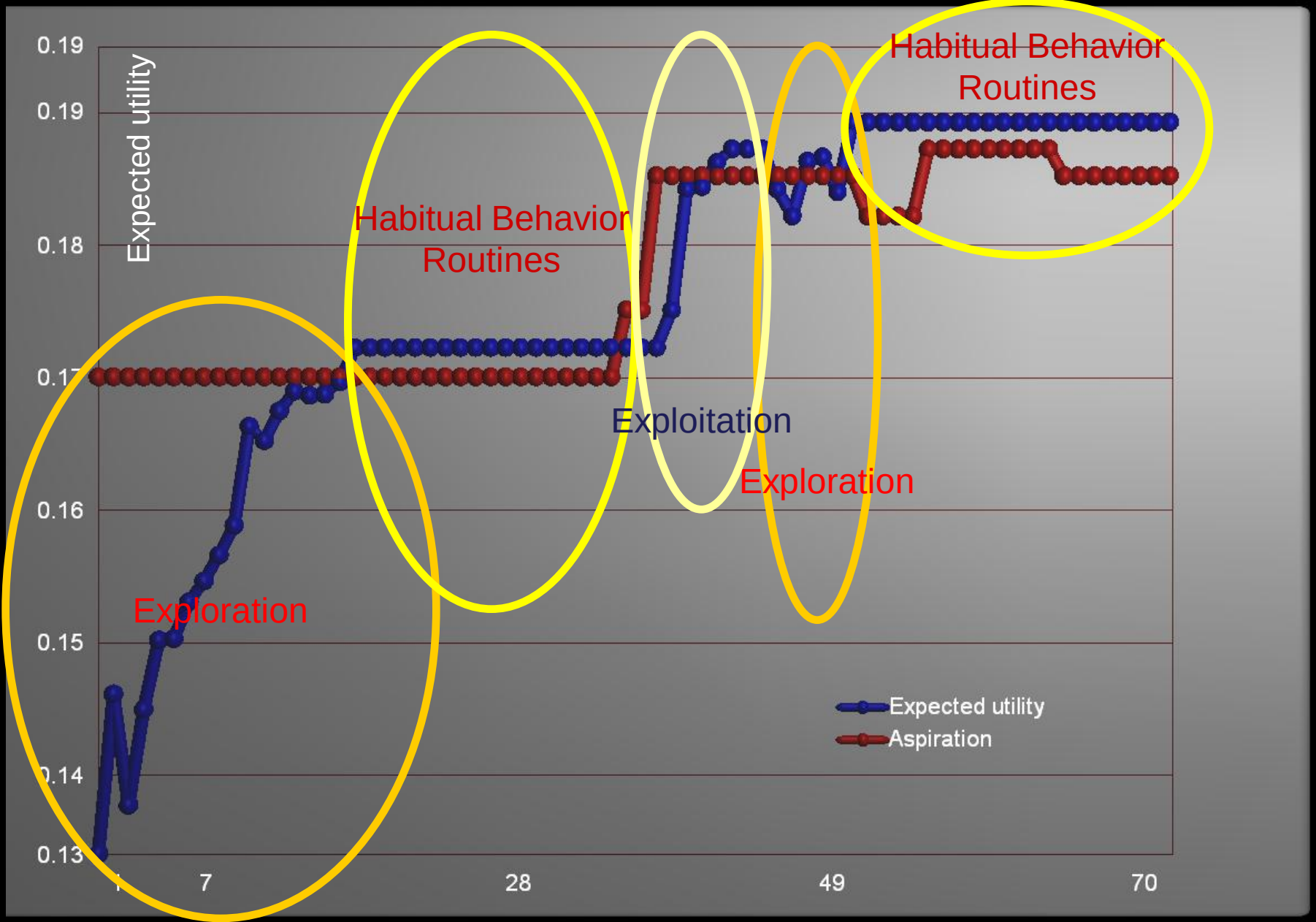
UPDATING PROCESS

Include in consideration set if

expected utility after exchange + threshold resistance to change > current expected utility

Process Model




Expected utility
0.19
0.19
0.18
0.17
0.16
0.15
0.14
0.13
1
7
28
49
70
Habitual Behavior Routines
Habitual Behavior Routines
Exploitation
Exploration
Exploration
Expected utility
Aspiration
Days

Simulation settings

- 100x100 cells with 100mx100m
- 6 agents, 72 days
- 1 activity a day – a shopping trip
- 8 context condition profiles
  - Origin of the trip (work/home)
  - Day of the week (weekday/weekend)
  - Time of the day (rush hour/non-rush hour)
- 12 shopping locations
  - 6 small, 4 medium, 2 big
  - 6 static attributes (Yes/no)
  - 1 dynamic attribute (crowdedness with 4 levels)

Simulation settings

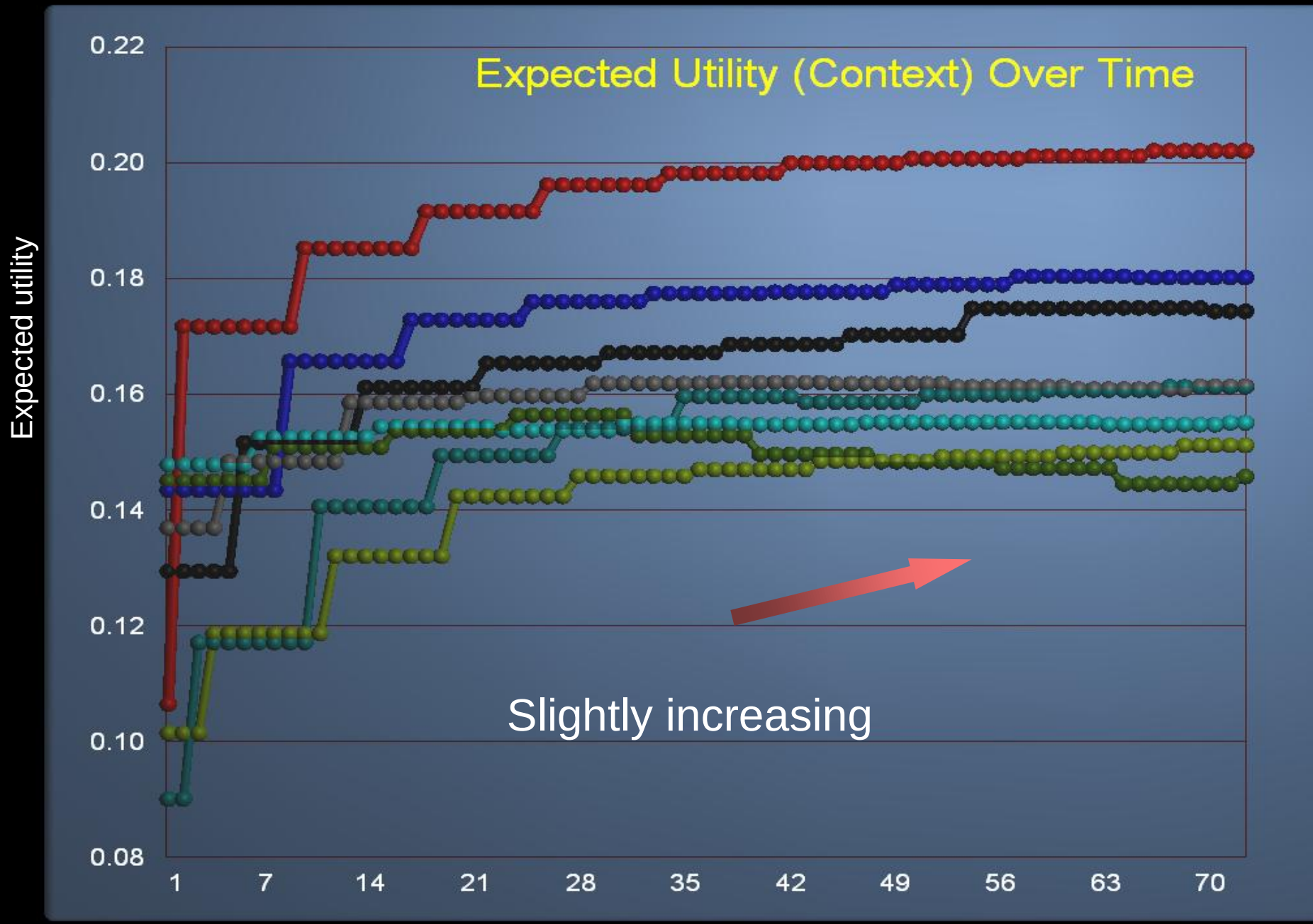
- Initial knowledge
  - Alternatives
  - Aspirations
- Cognitive learning
  - Conditional updating
  - Boltzmann model
- Social learning
  - One-way directed contact
  - 8-day interval contact
- Average 100 simulation run

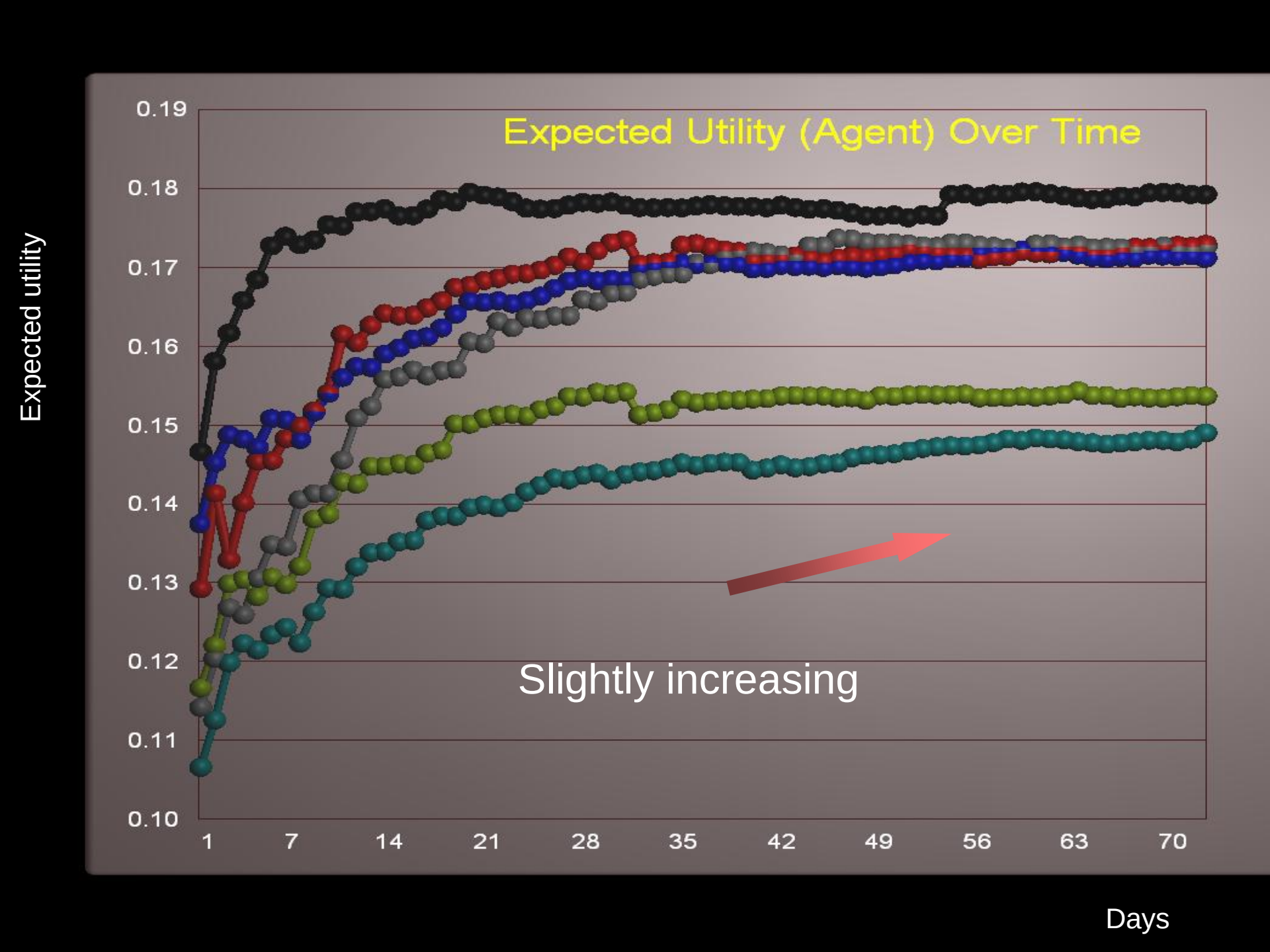
Simulation settings

- Cognitive learning parameters
  - Minimum activation level
  - Maximum exploration effort
  - Aspiration dissatisfaction tolerance
- Social learning parameters
  - Social deviation tolerance
  - Information acceptance
- Social contact scenarios

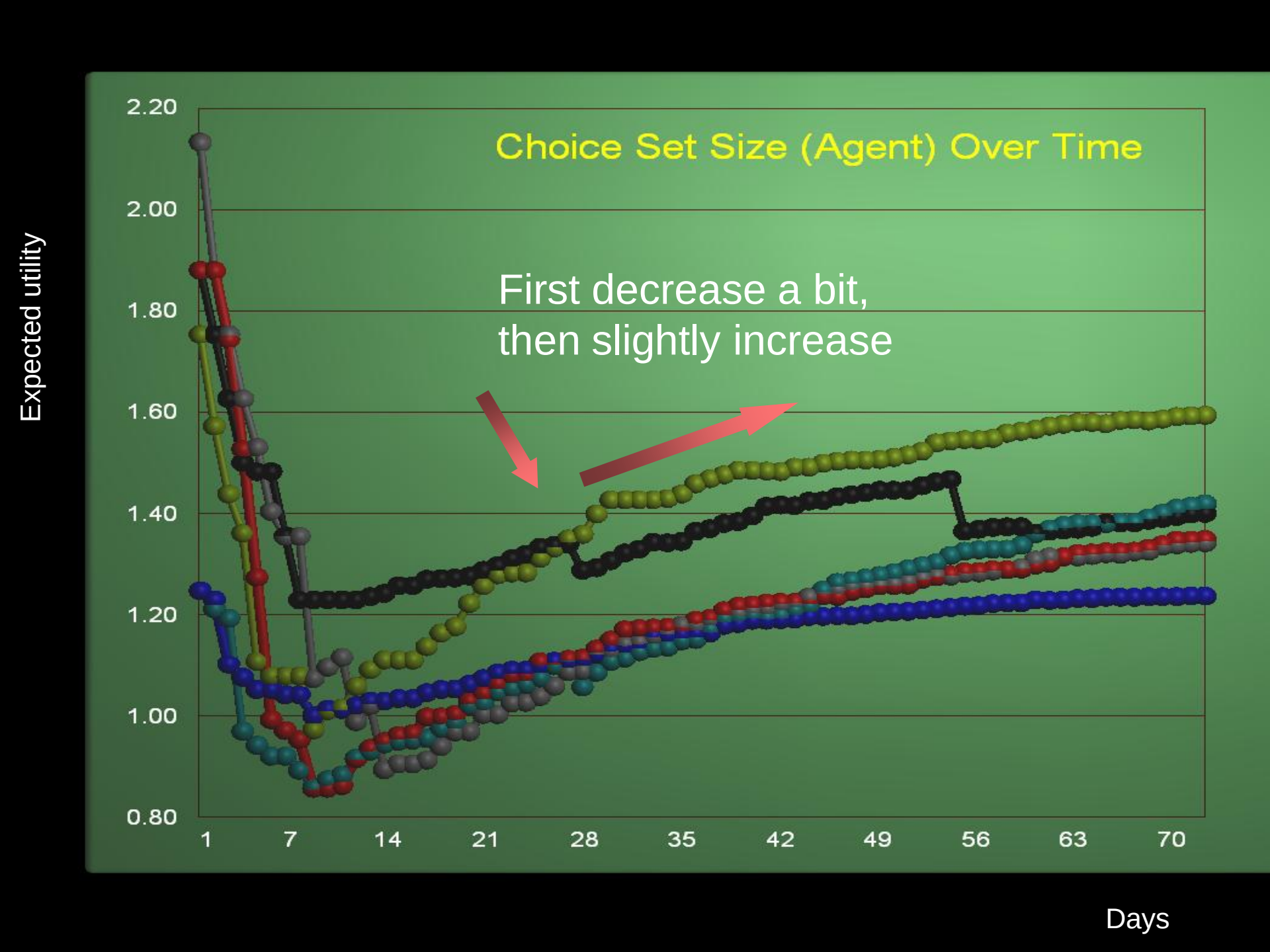
Properties

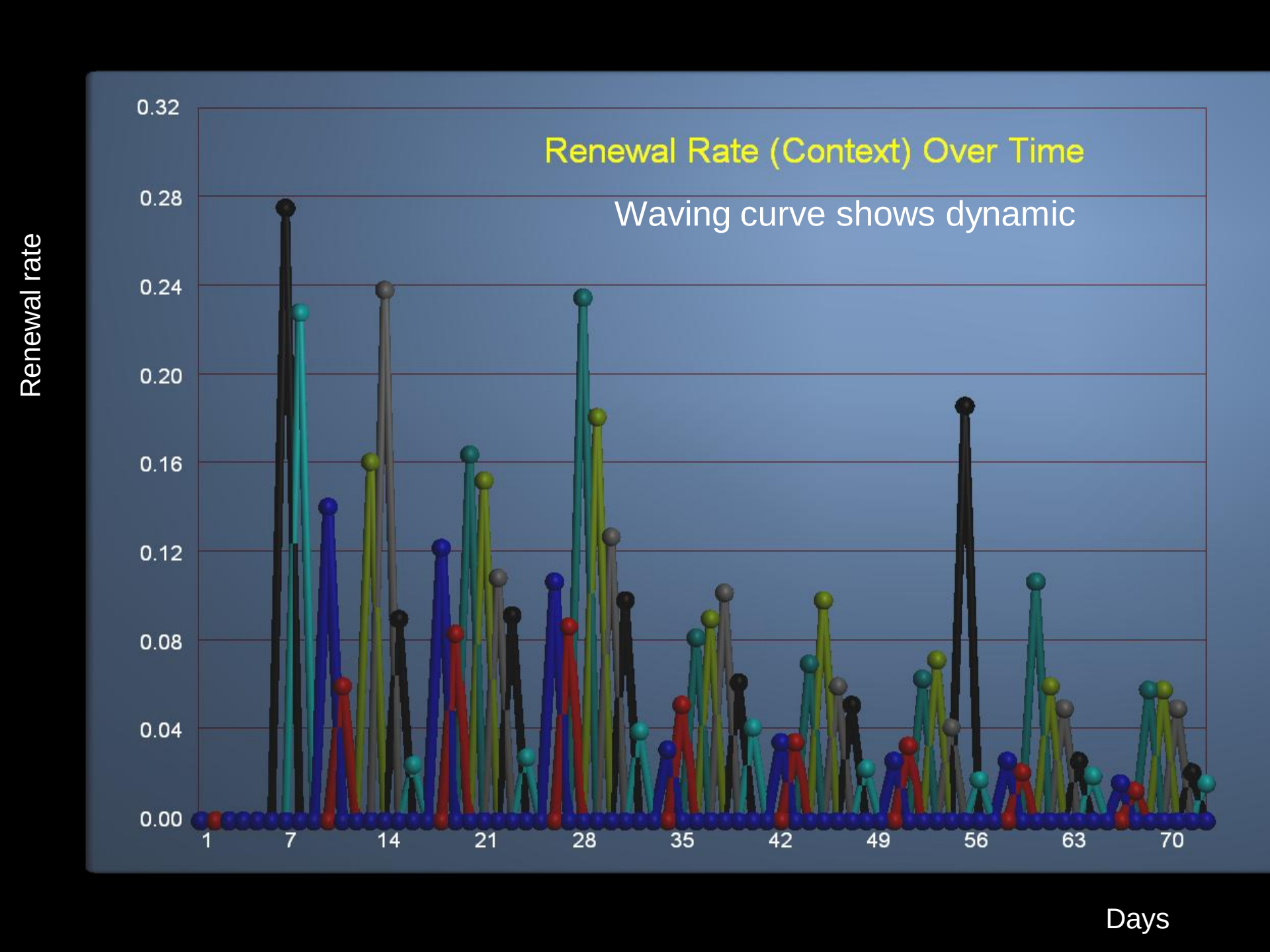
Dynamics

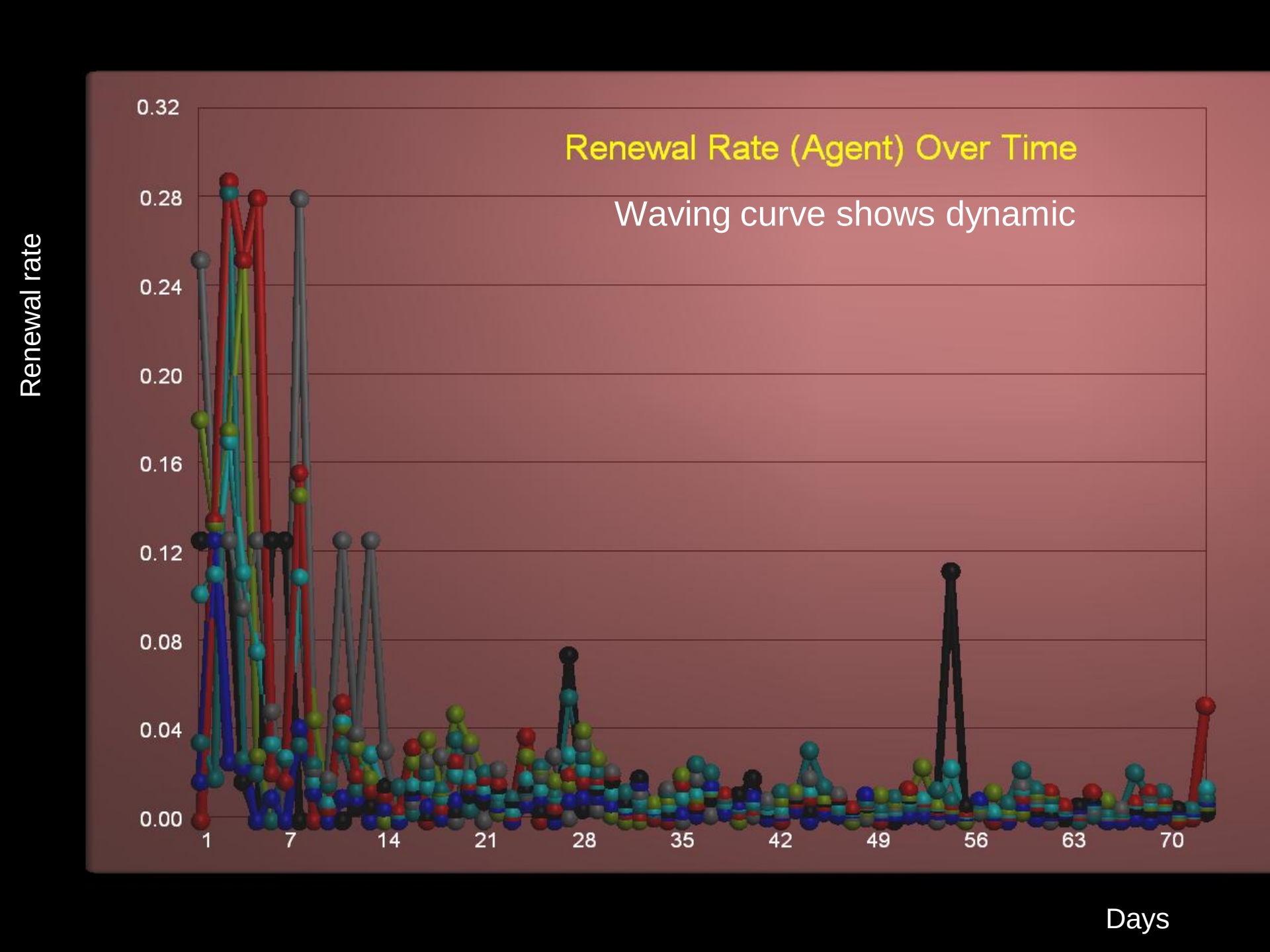

Expected Utility (Context) Over Time
Expected utility
0.22
0.20
0.18
0.16
0.14
0.12
0.10
0.08
1
7
14
21
28
35
42
49
56
63
70
Slightly increasing
Days


Expected Utility (Agent) Over Time
Expected utility
0.19
0.18
0.17
0.16
0.15
0.14
0.13
0.12
0.11
0.10
1
7
14
21
28
35
42
49
56
63
70
Slightly increasing
Days


Choice Set Size (Context) Over Time
First decrease a bit,
then slightly increase
Expected utility
1.90
1.80
1.60
1.40
1.20
1.00
0.80
1
7
14
21
28
35
42
49
56
63
70
Days

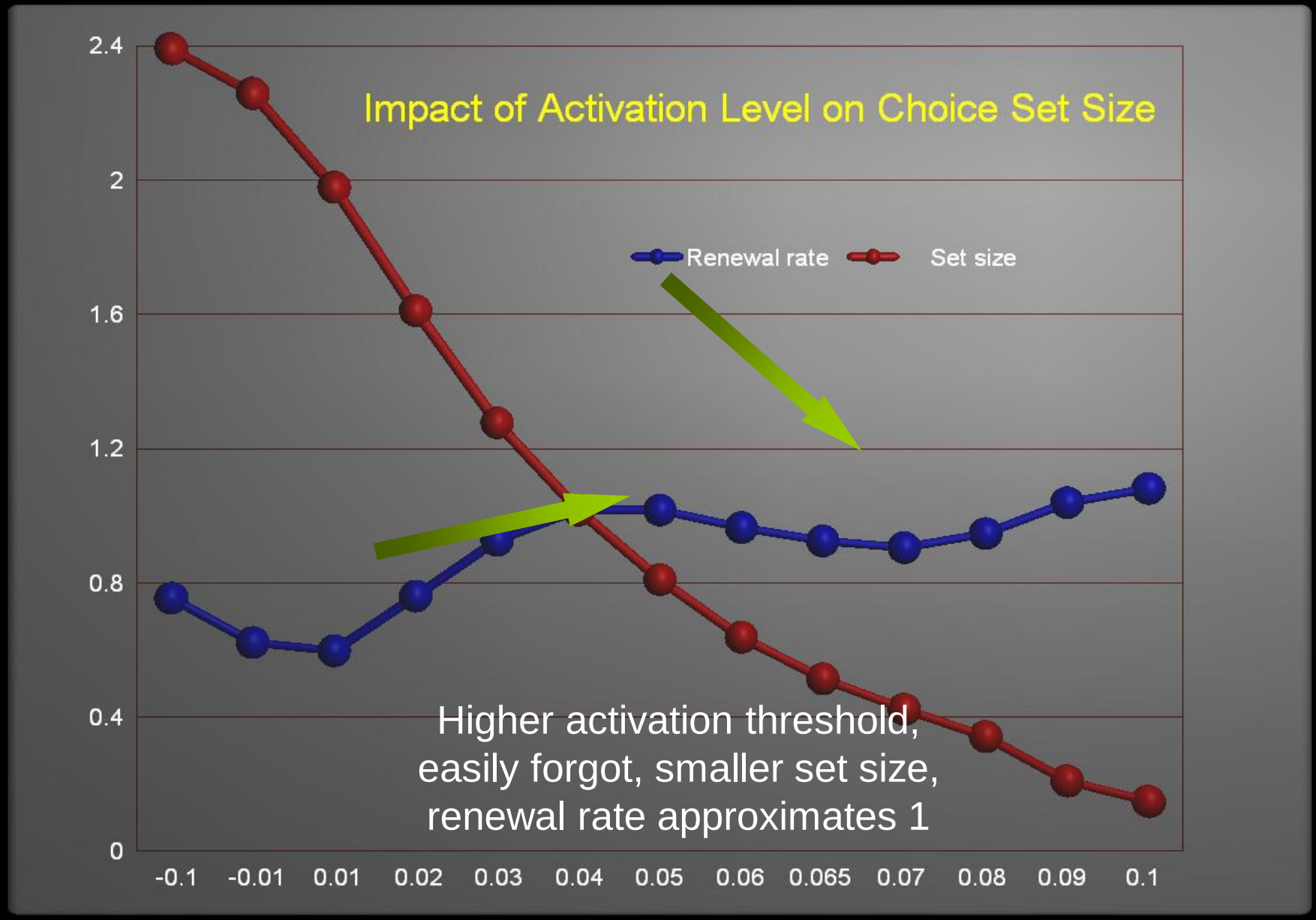

Choice Set Size (Agent) Over Time
First decrease a bit,
then slightly increase
Expected utility
2.20
2.00
1.80
1.60
1.40
1.20
1.00
0.80
1
7
14
21
28
35
42
49
56
63
70
Days


Renewal Rate (Context) Over Time
Waving curve shows dynamic
Renewal rate
0.32
0.28
0.24
0.20
0.16
0.12
0.08
0.04
0.00
1
7
14
21
28
35
42
49
56
63
70
Days


Renewal Rate (Agent) Over Time
Waving curve shows dynamic
Renewal rate
0.32
0.28
0.24
0.20
0.16
0.12
0.08
0.04
0.00
1
7
14
21
28
35
42
49
56
63
70
Days

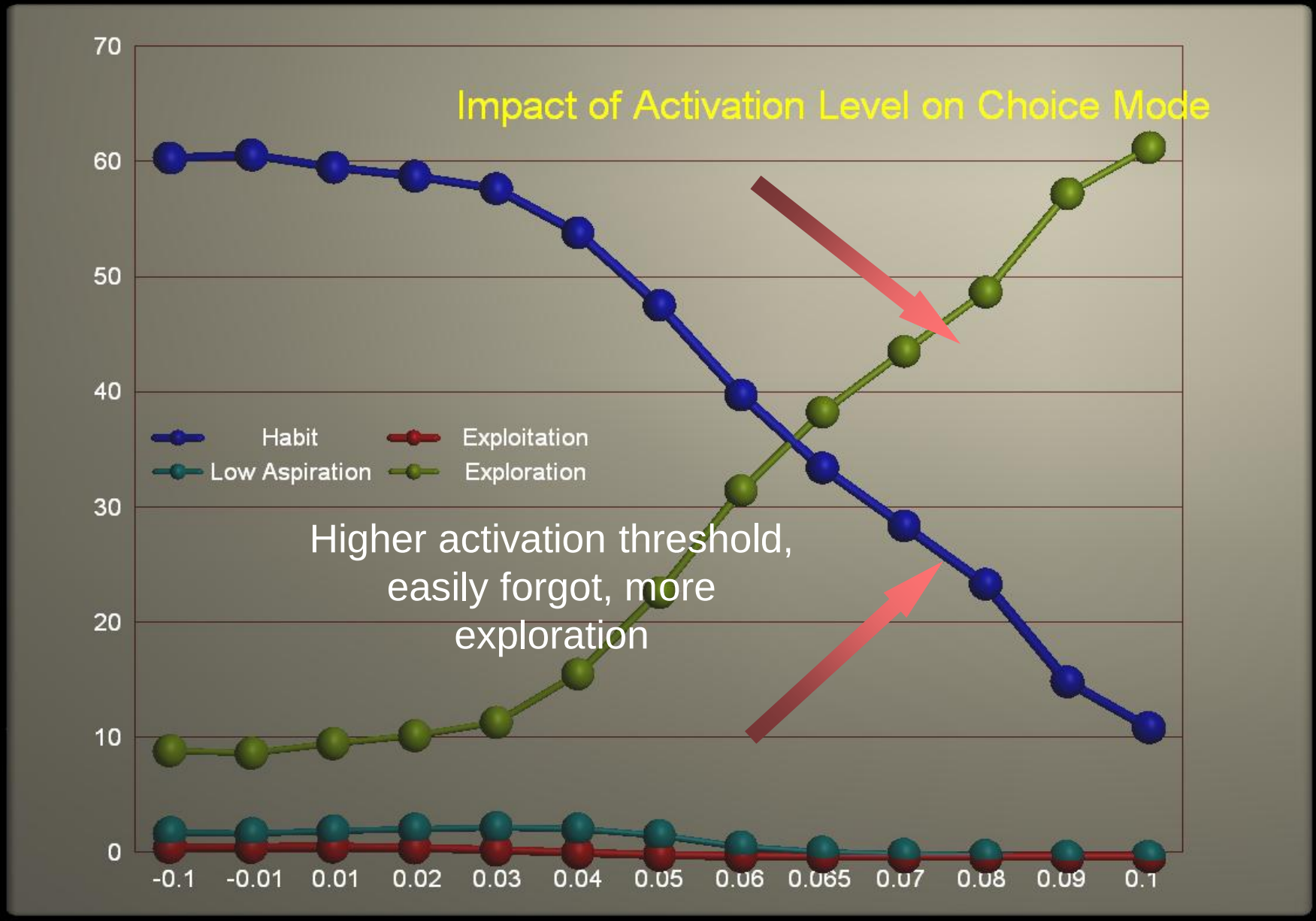
Properties

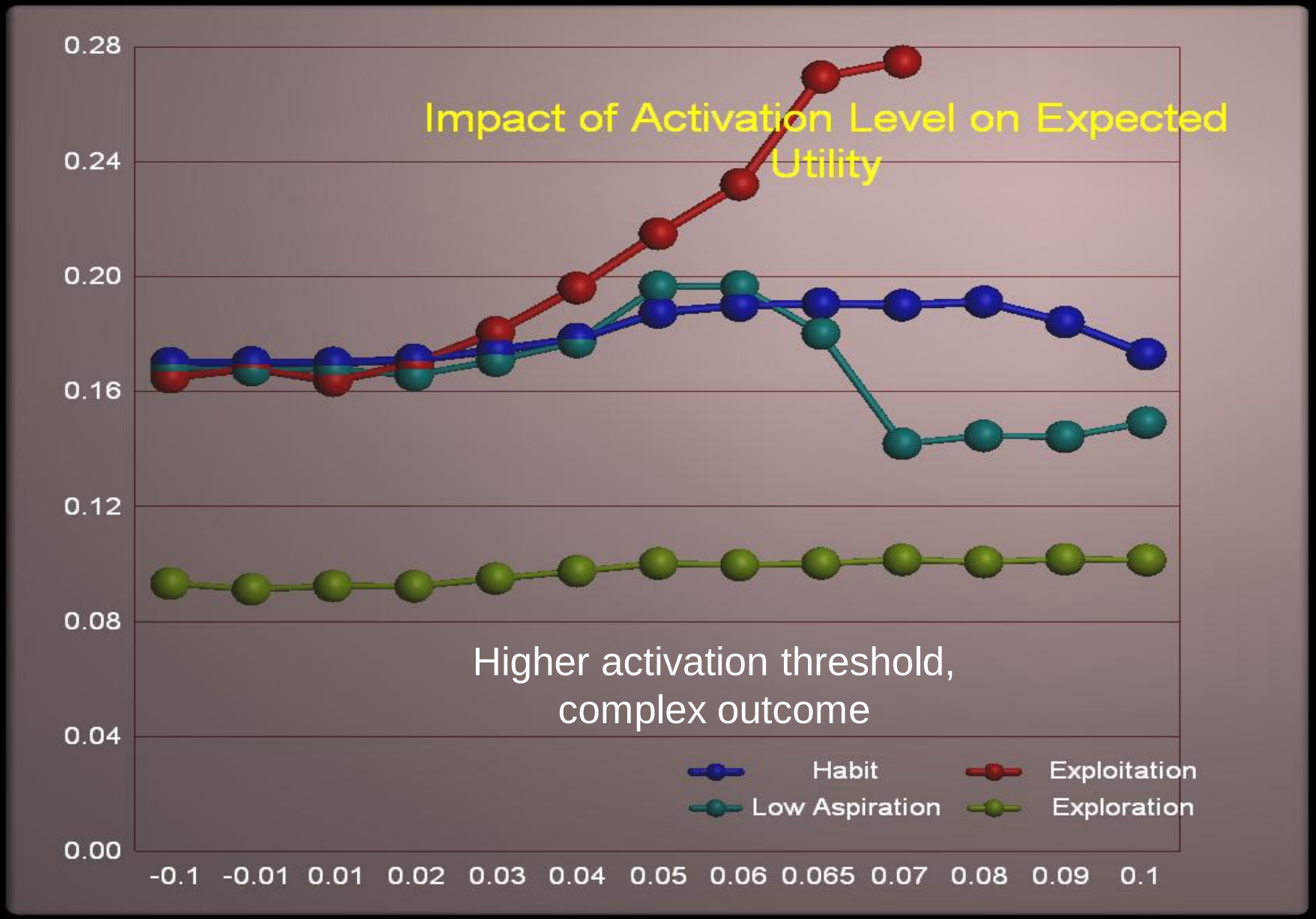
Impact of activation level

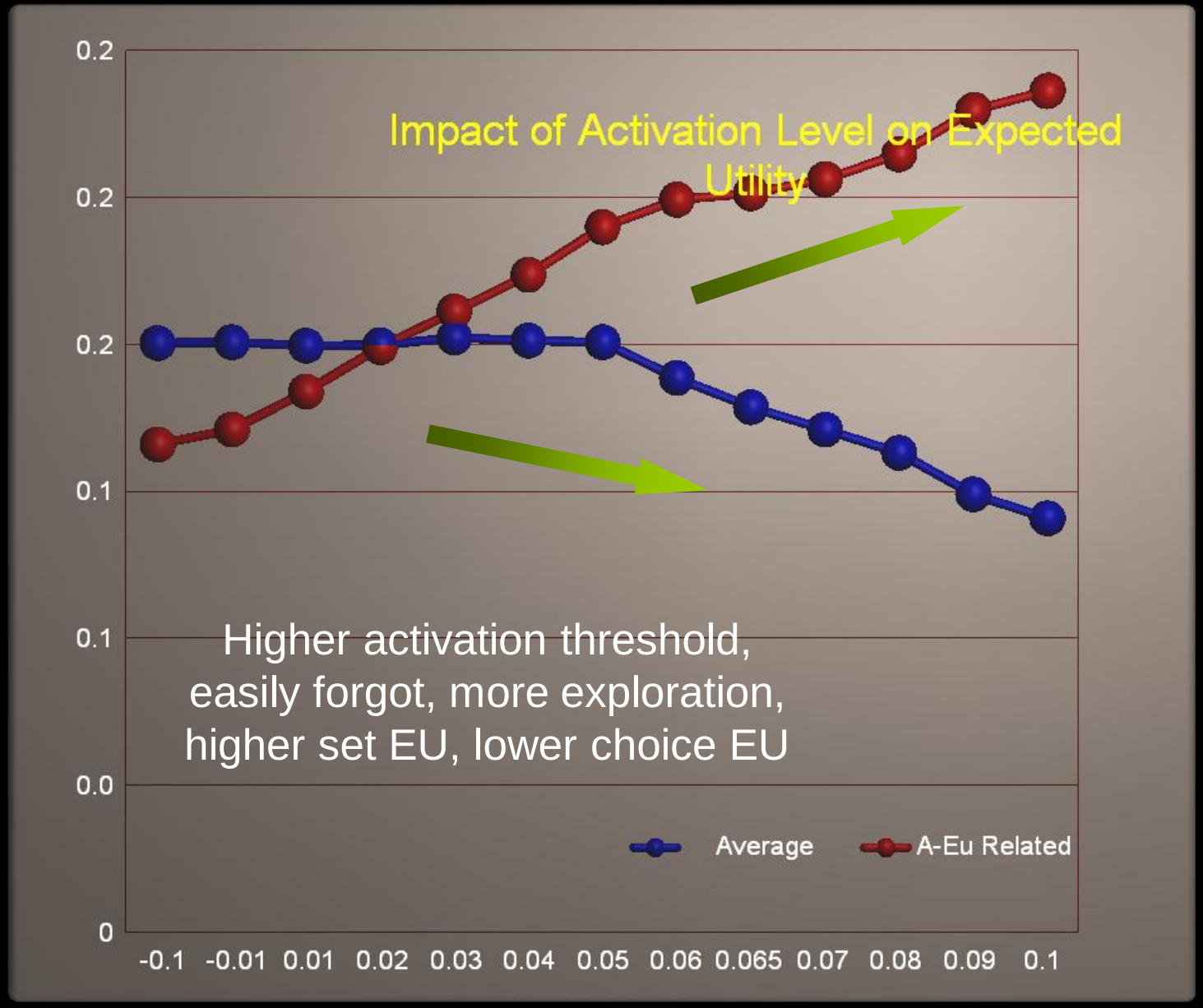


Choice set size

Activation level threshold


Impact of Activation Level on Choice Mode
Number of choices
70
60
50
40
30
20
10
0
Habit
Exploitation
Low Aspiration
Exploration
Higher activation threshold, easily forgot, more exploration
-0.1
-0.01
0.01
0.02
0.03
0.04
0.05
0.06
0.065
0.07
0.08
0.09
0.1
Activation level threshold


Impact of Activation Level on Expected Utility
Expected utility
0.28
0.24
0.20
0.16
0.12
0.08
0.04
0.00
-0.1
-0.01
0.01
0.02
0.03
0.04
0.05
0.06
0.065
0.07
0.08
0.09
0.1
Higher activation threshold, complex outcome
Habit
Exploitation
Low Aspiration
Exploration
Activation level threshold

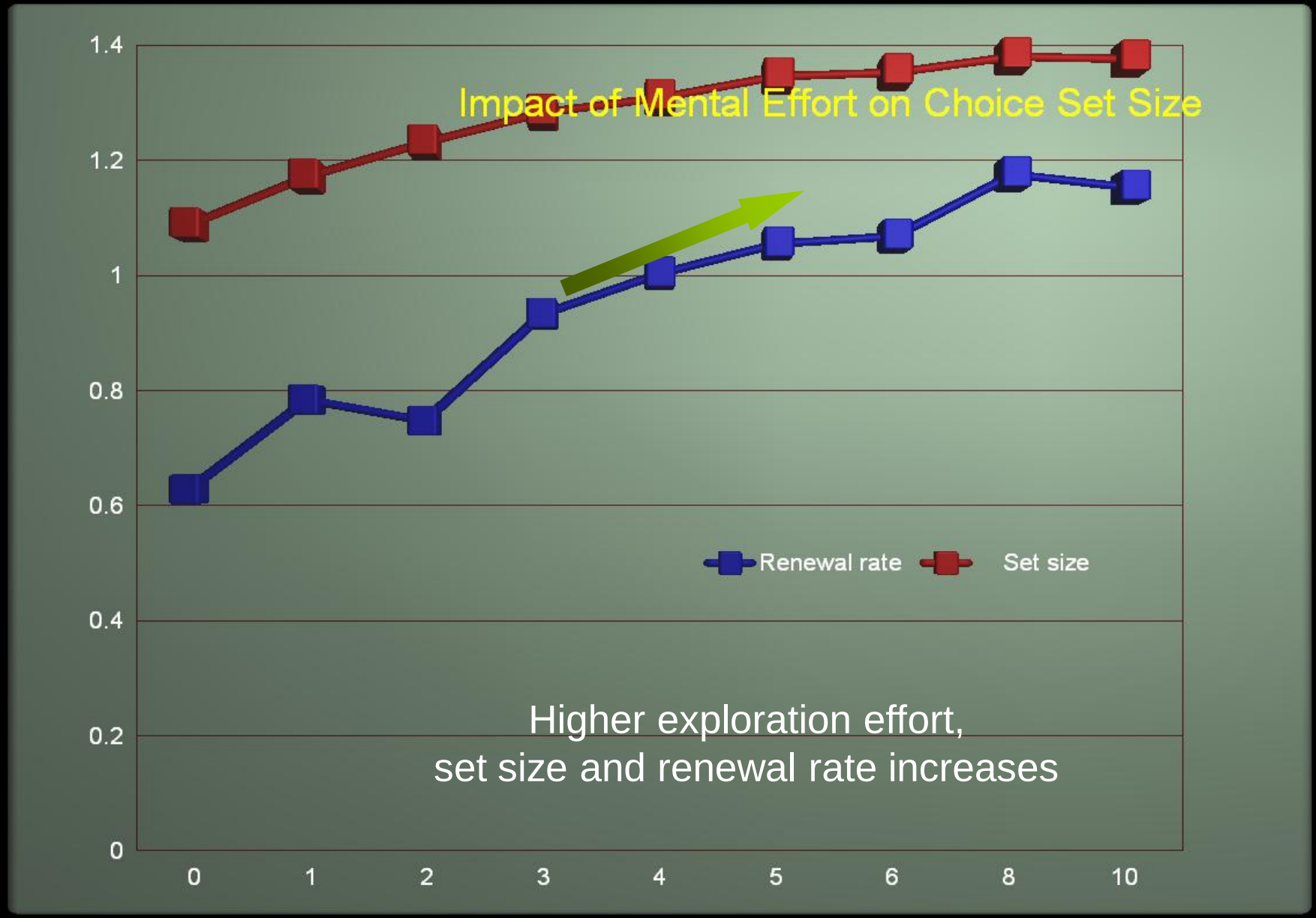


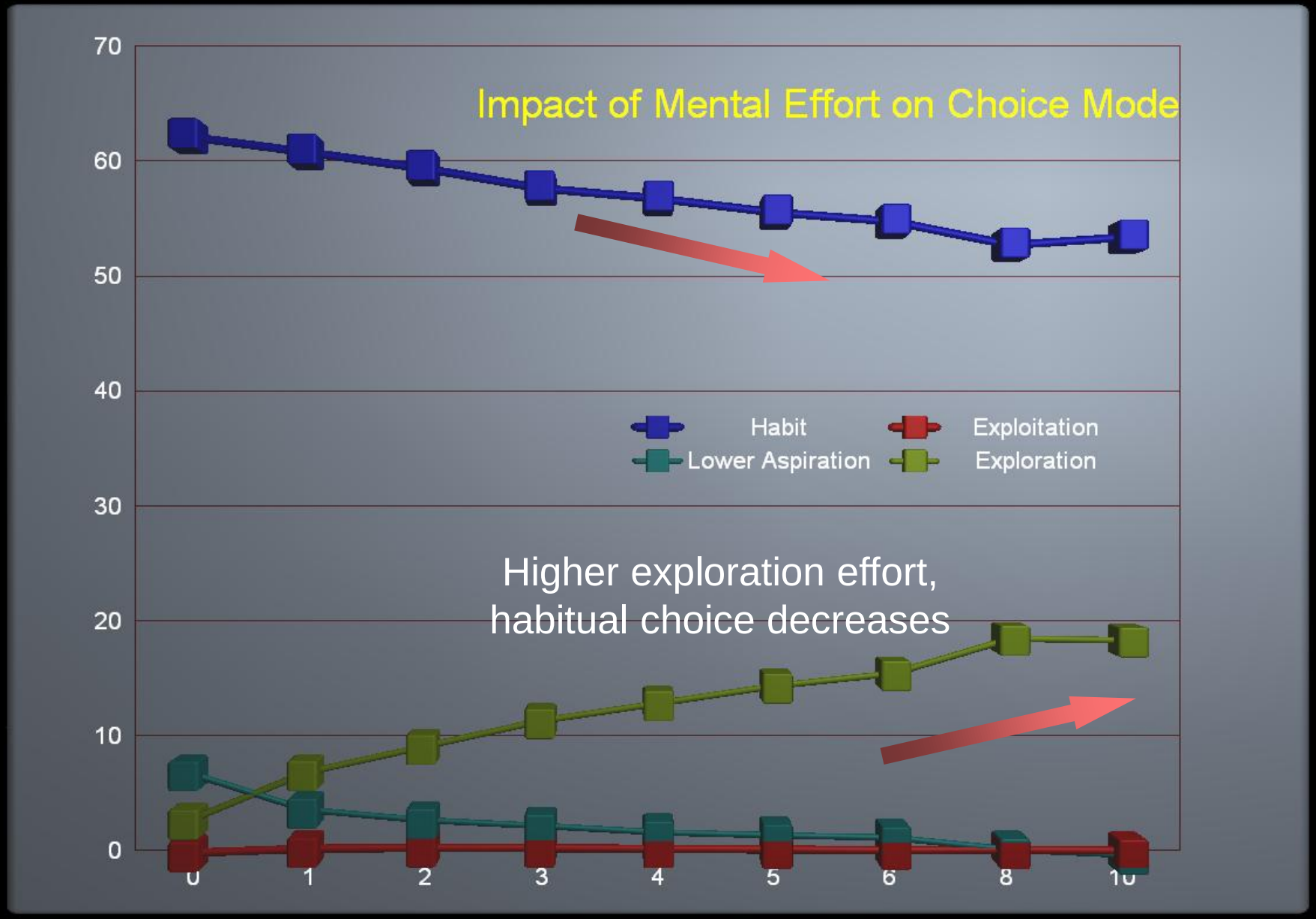
Expected utility

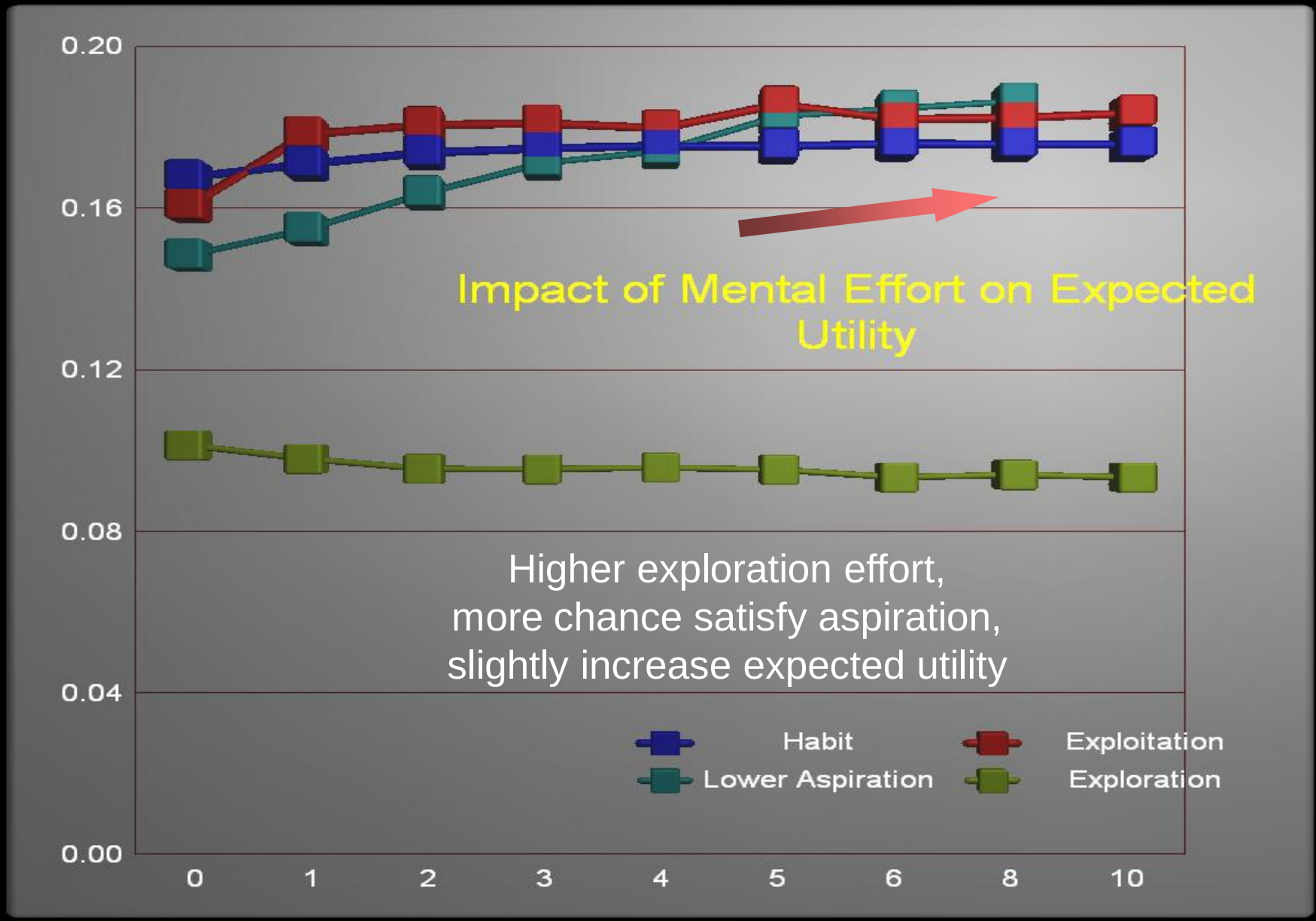
Activation level threshold

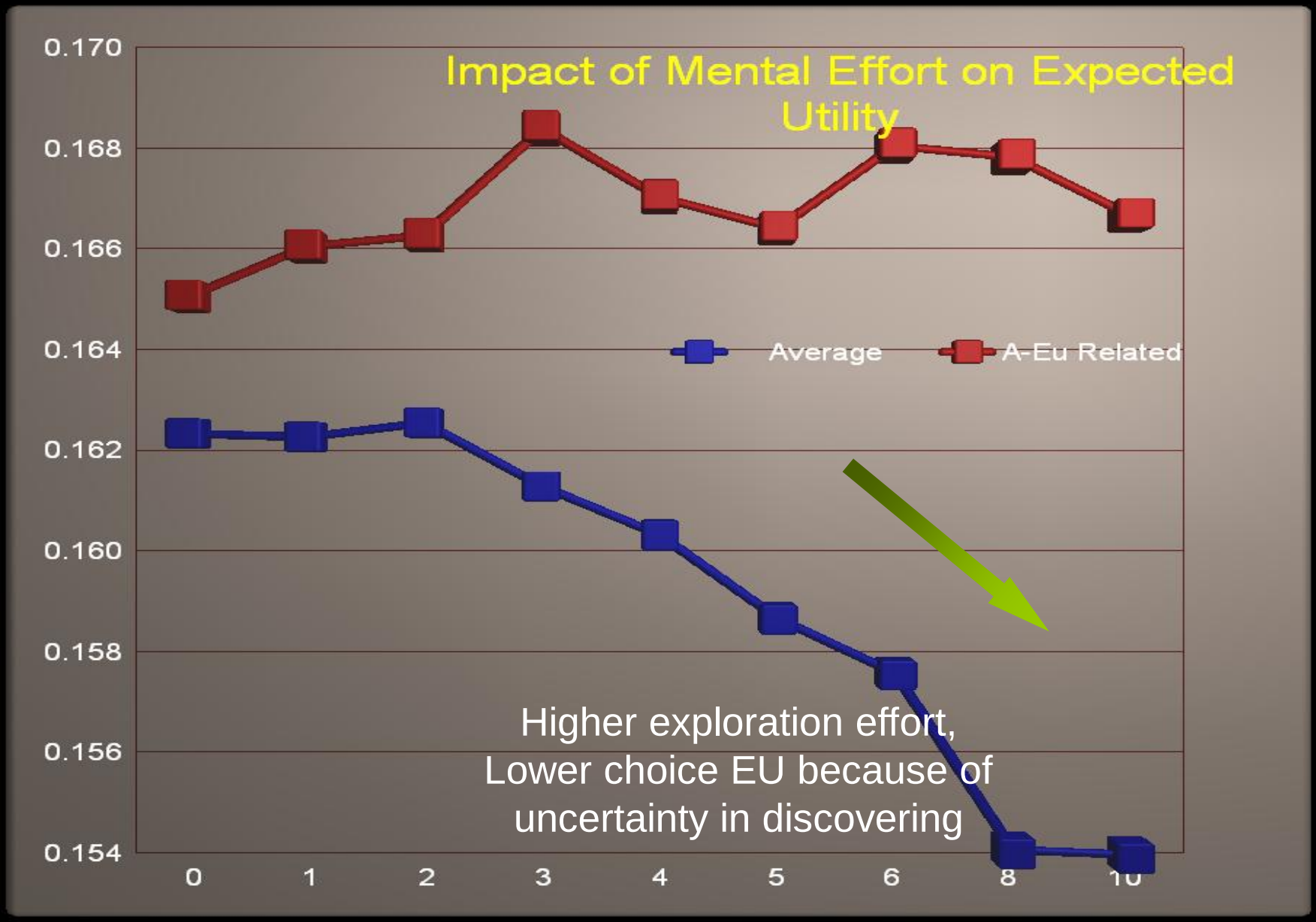
Properties

Impact of mental effort


Impact of Mental Effort on Choice Set Size
Number of alternatives
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
1
2
3
4
5
6
8
10
Renewal rate
Set size
Higher exploration effort,
set size and renewal rate increases
Maximum exploration effort

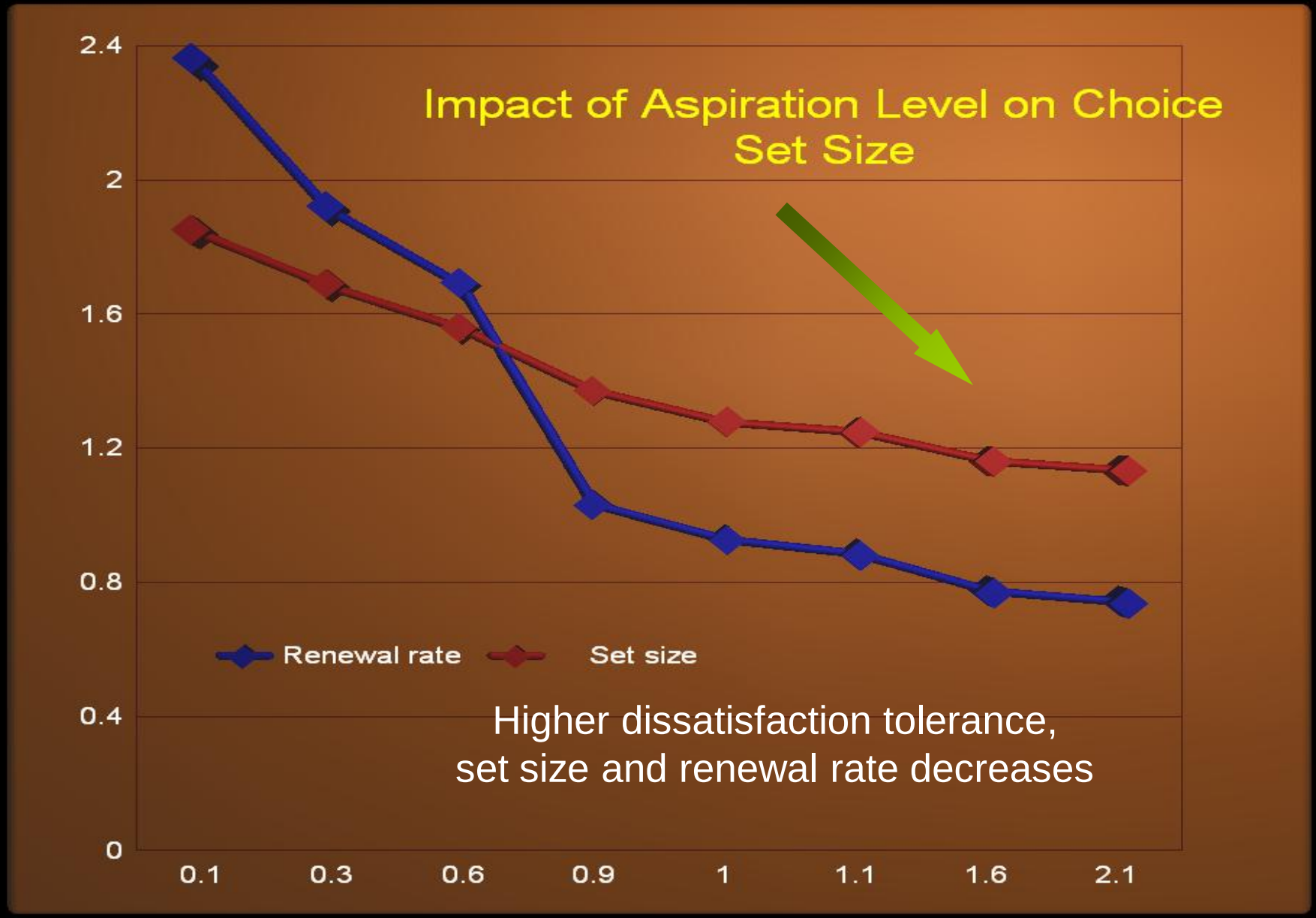

Impact of Mental Effort on Choice Mode
Number of alternatives
70
60
50
40
30
20
10
0
Habit
Exploitation
Lower Aspiration
Exploration
Higher exploration effort,
habitual choice decreases
0
1
2
3
4
5
6
8
10
Maximum exploration effort


Expected utility
0.20
0.16
0.12
0.08
0.04
0.00
0
1
2
3
4
5
6
8
10
Impact of Mental Effort on Expected Utility
Higher exploration effort,
more chance satisfy aspiration,
slightly increase expected utility
Habit
Lower Aspiration
Exploitation
Exploration
Maximum exploration effort


Impact of Mental Effort on Expected Utility
Expected utility
0.170
0.168
0.166
0.164
0.162
0.160
0.158
0.156
0.154
Average
A-Eu Related
Higher exploration effort,
Lower choice EU because of
uncertainty in discovering
0
1
2
3
4
5
6
8
10
Maximum exploration effort

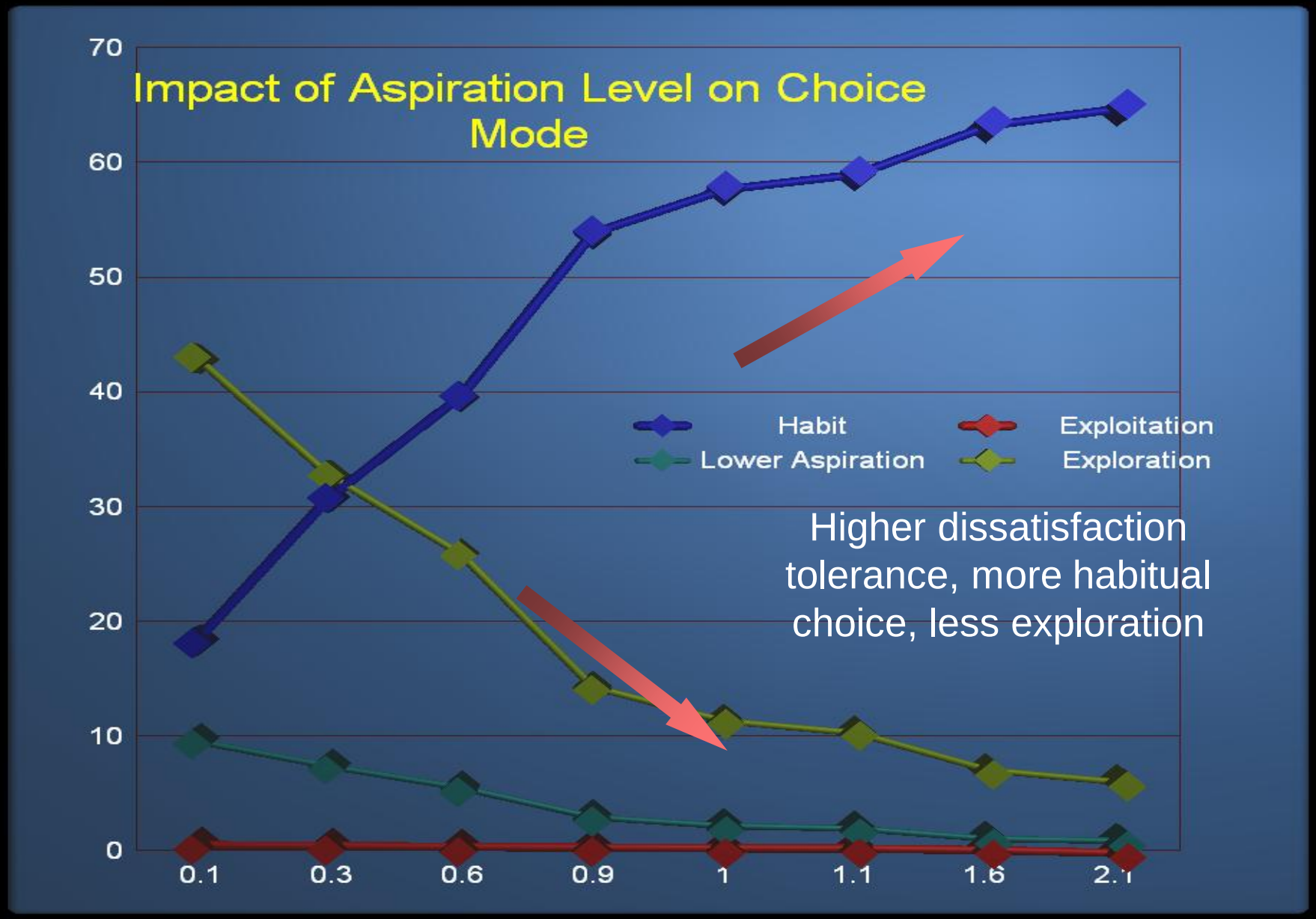
Properties

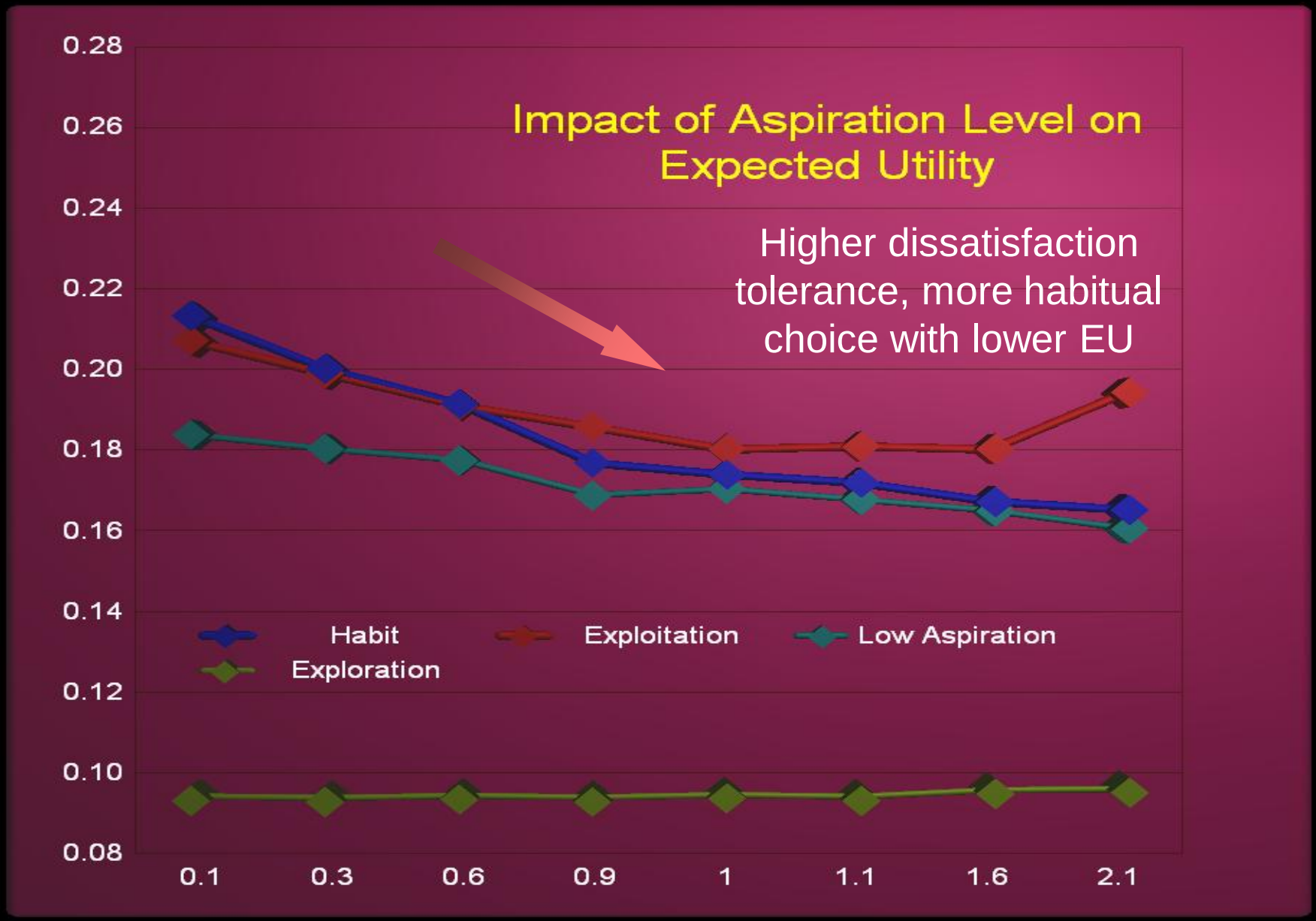
Impact of aspiration level

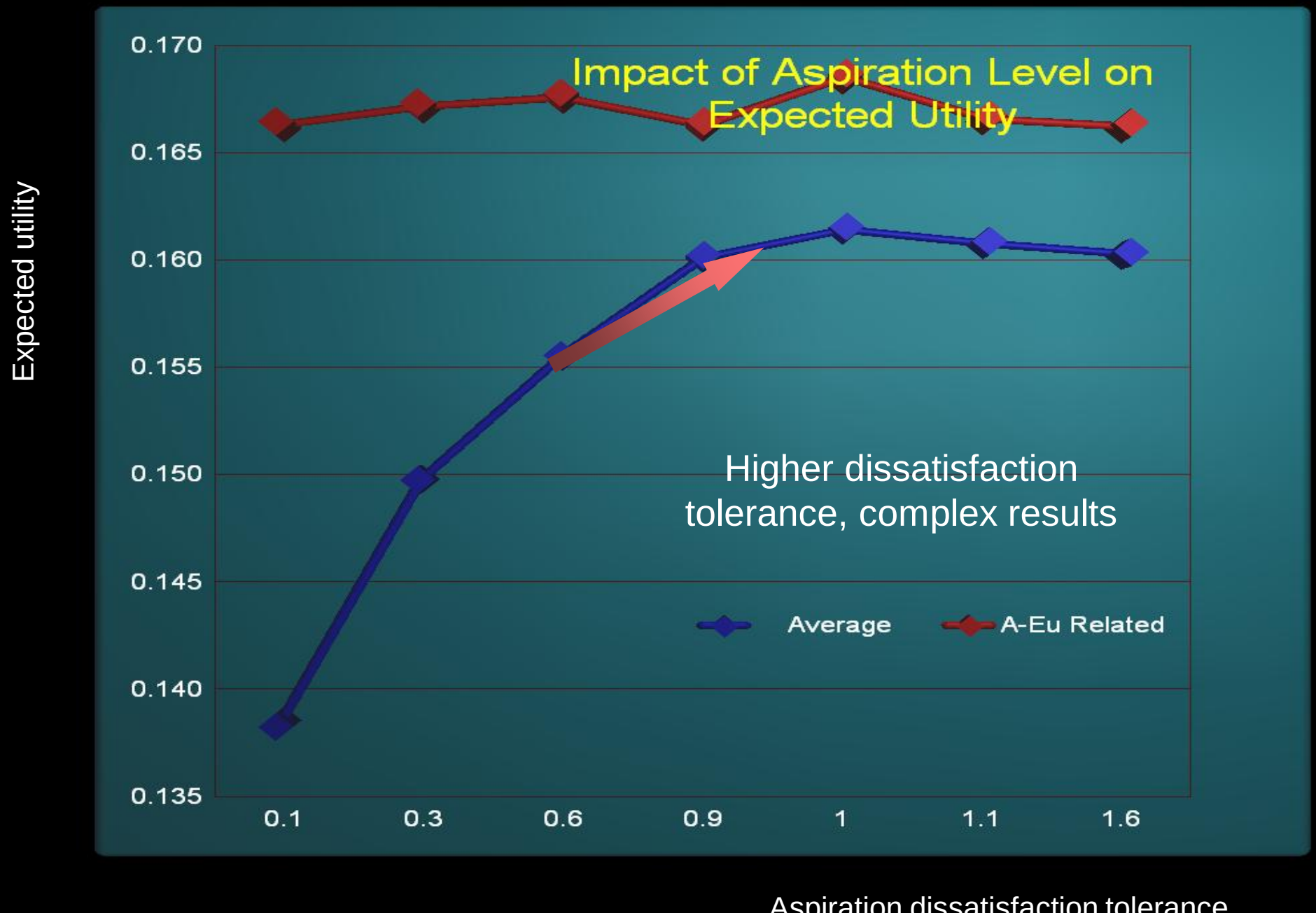


Number of alternatives

Aspiration dissatisfaction tolerance

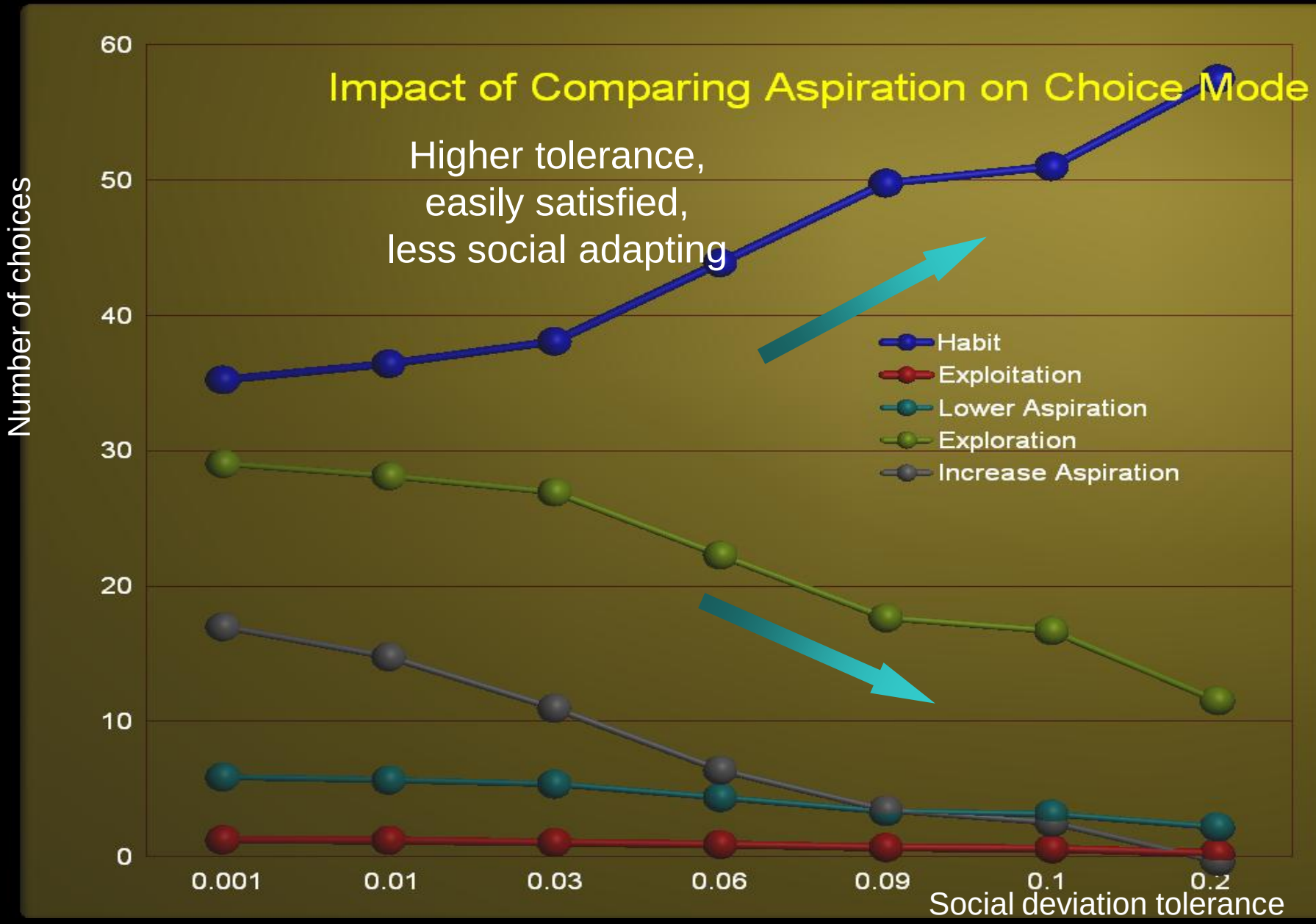

Impact of Aspiration Level on Choice Mode
Number of alternatives
70
60
50
40
30
20
10
0
0.1
0.3
0.6
0.9
1
1.1
1.6
2.1
Habit
Lower Aspiration
Exploitation
Exploration
Higher dissatisfaction tolerance, more habitual choice, less exploration
Aspiration dissatisfaction tolerance

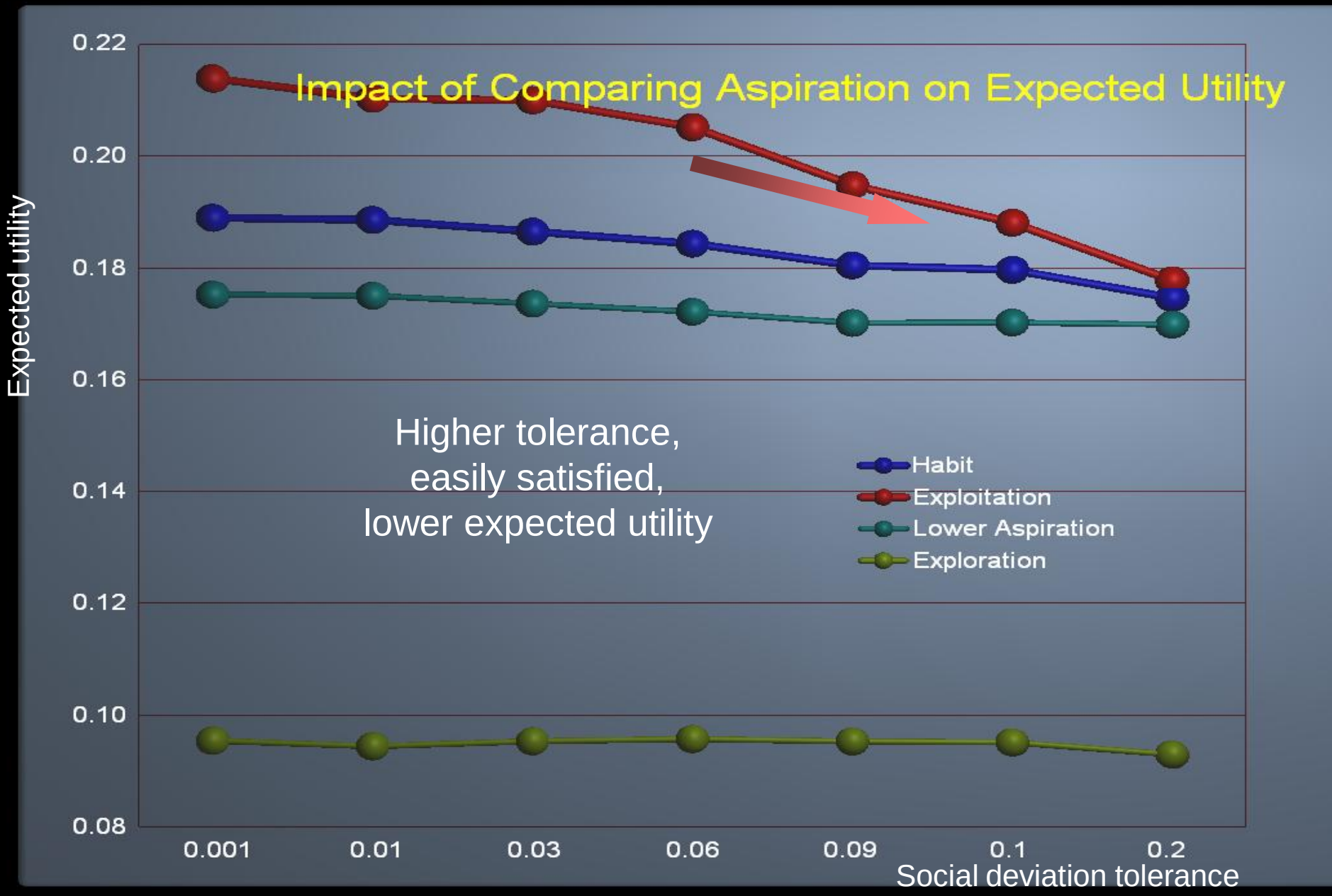

Impact of Aspiration Level on Expected Utility
Higher dissatisfaction tolerance, more habitual choice with lower EU
Habit
Exploitation
Low Aspiration
Exploration
0.28
0.26
0.24
0.22
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.1
0.3
0.6
0.9
1
1.1
1.6
2.1
Expected utility
Aspiration dissatisfaction tolerance

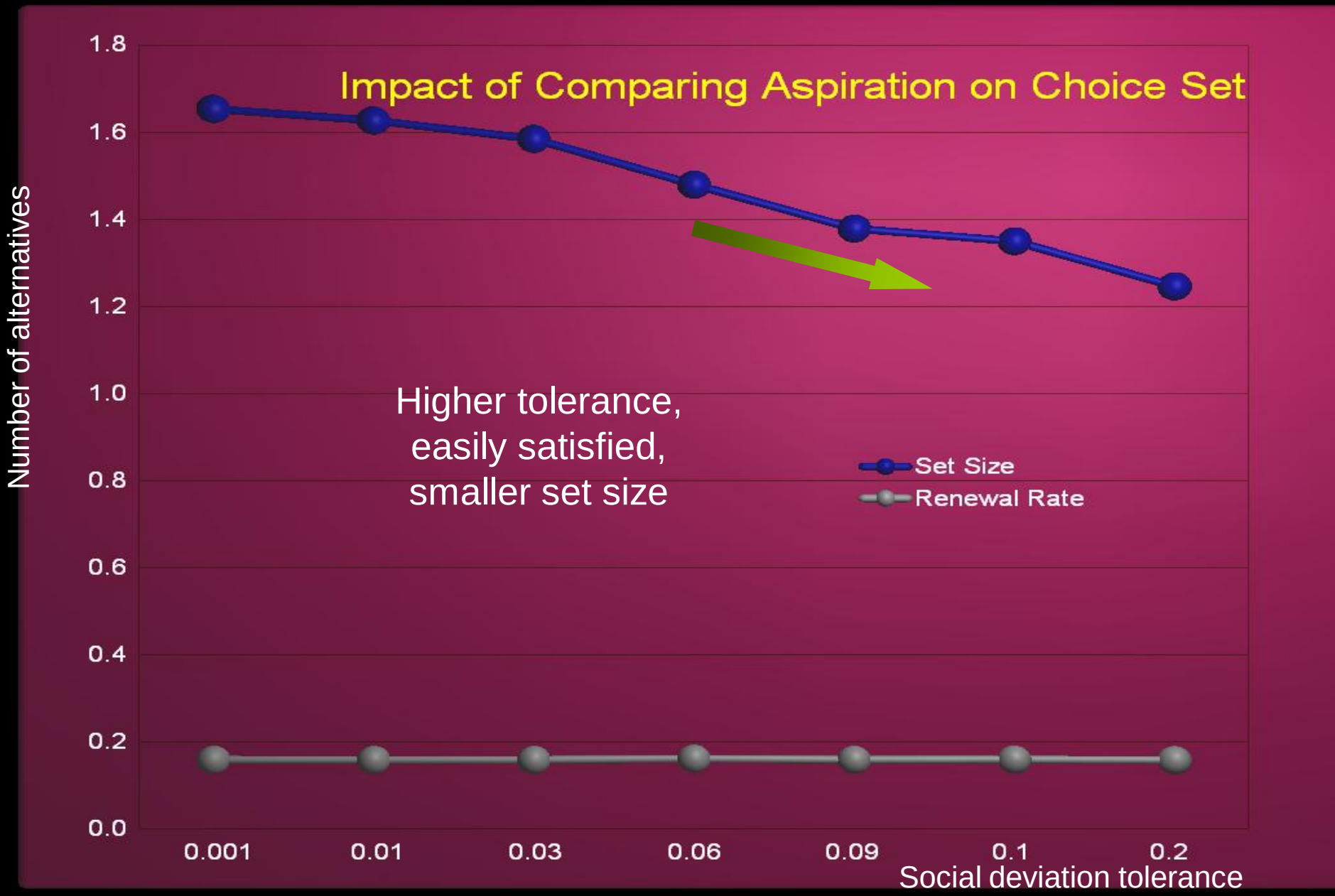

Impact of Aspiration Level on Expected Utility
Expected utility
0.170
0.165
0.160
0.155
0.150
0.145
0.140
0.135
0.1
0.3
0.6
0.9
1
1.1
1.6
Higher dissatisfaction tolerance, complex results
Average
A-Eu Related
Aspiration dissatisfaction tolerance

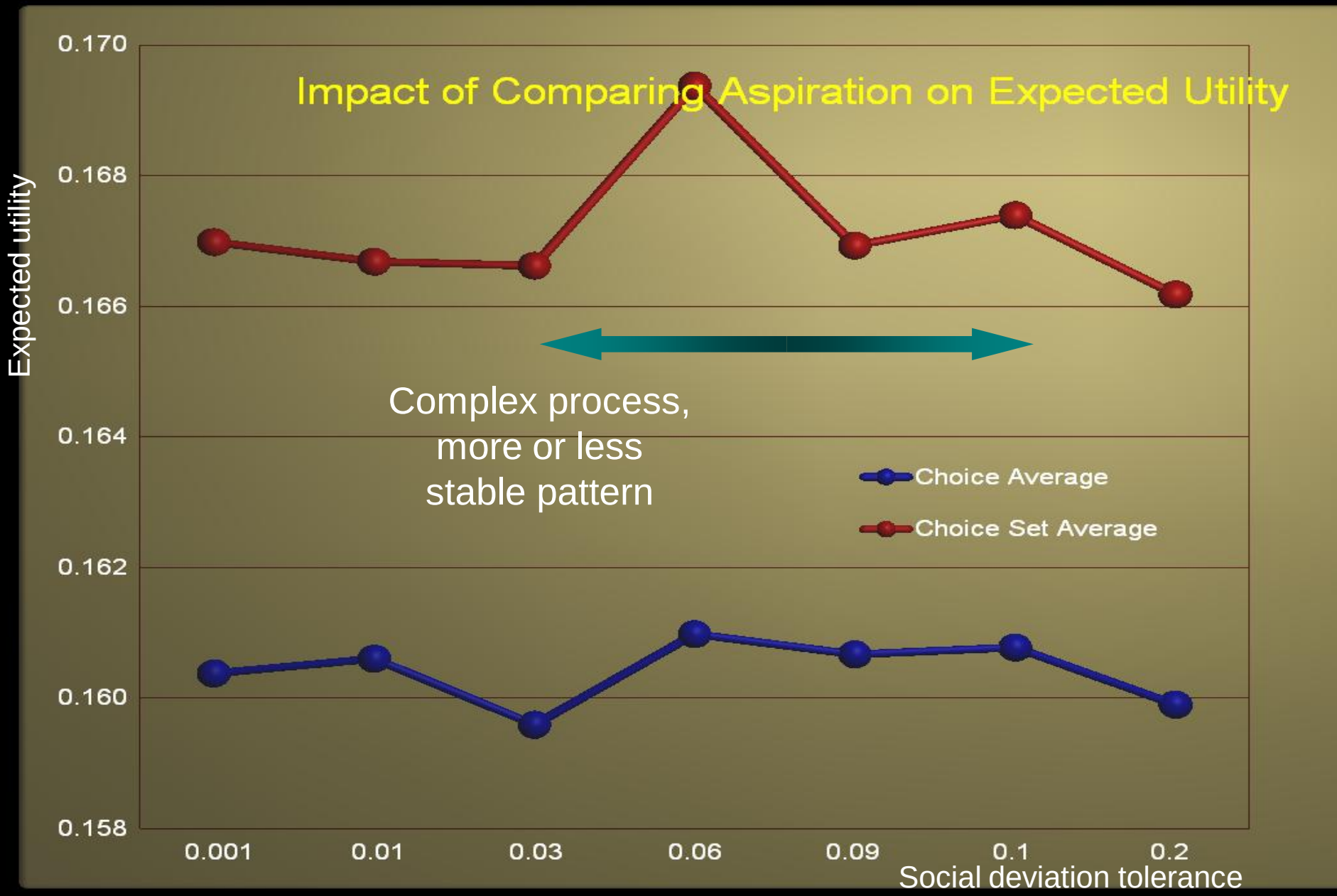
Properties

- Impact of social deviation tolerance


Impact of Comparing Aspiration on Choice Mode
Higher tolerance,
easily satisfied,
less social adapting
Habit
Exploitation
Lower Aspiration
Exploration
Increase Aspiration
Number of choices
60
50
40
30
20
10
0
0.001
0.01
0.03
0.06
0.09
0.1
0.2
Social deviation tolerance

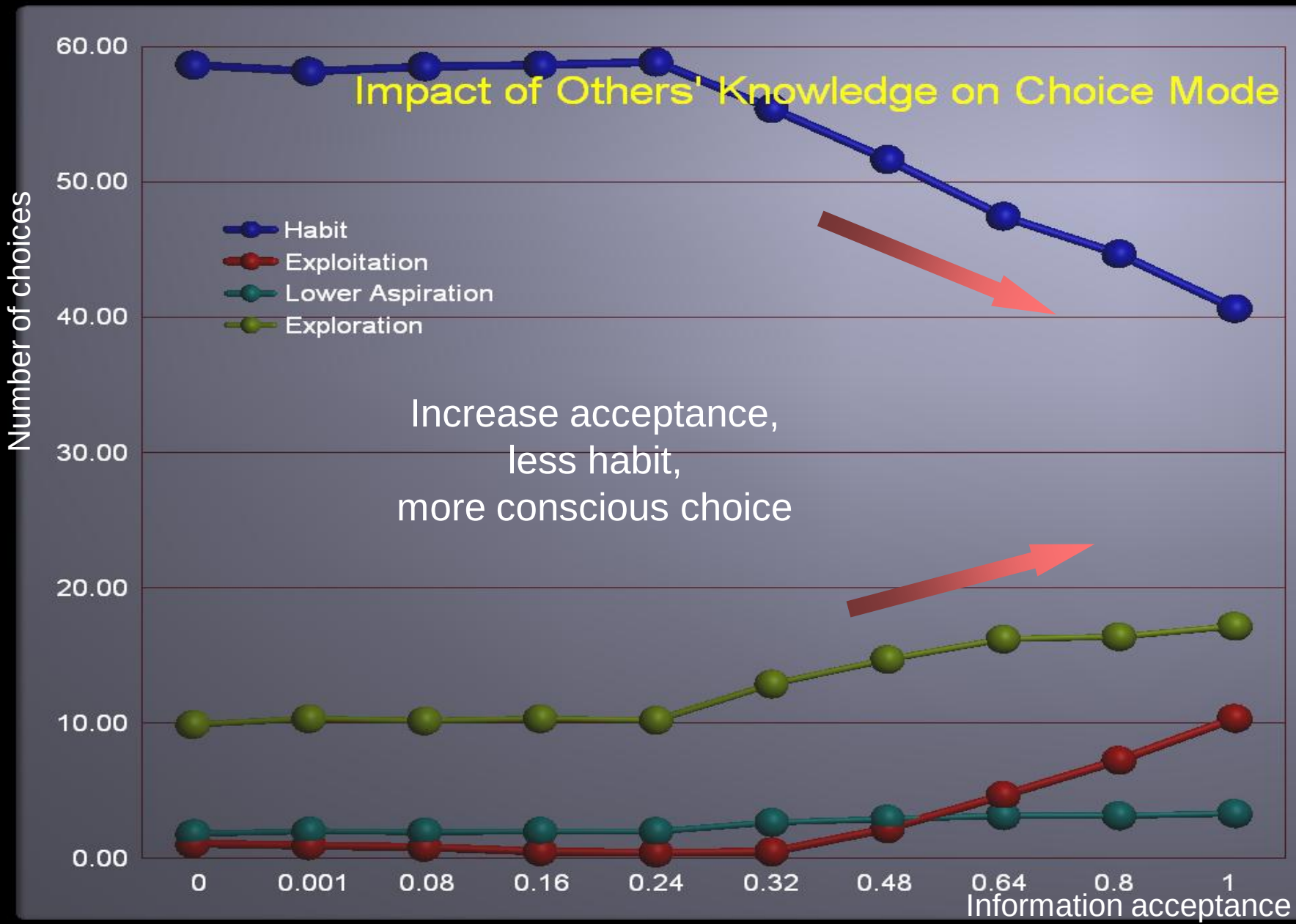

Impact of Comparing Aspiration on Expected Utility
Expected utility
0.22
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.001
0.01
0.03
0.06
0.09
0.1
0.2
Social deviation tolerance
Higher tolerance,
easily satisfied,
lower expected utility
Habit
Exploitation
Lower Aspiration
Exploration

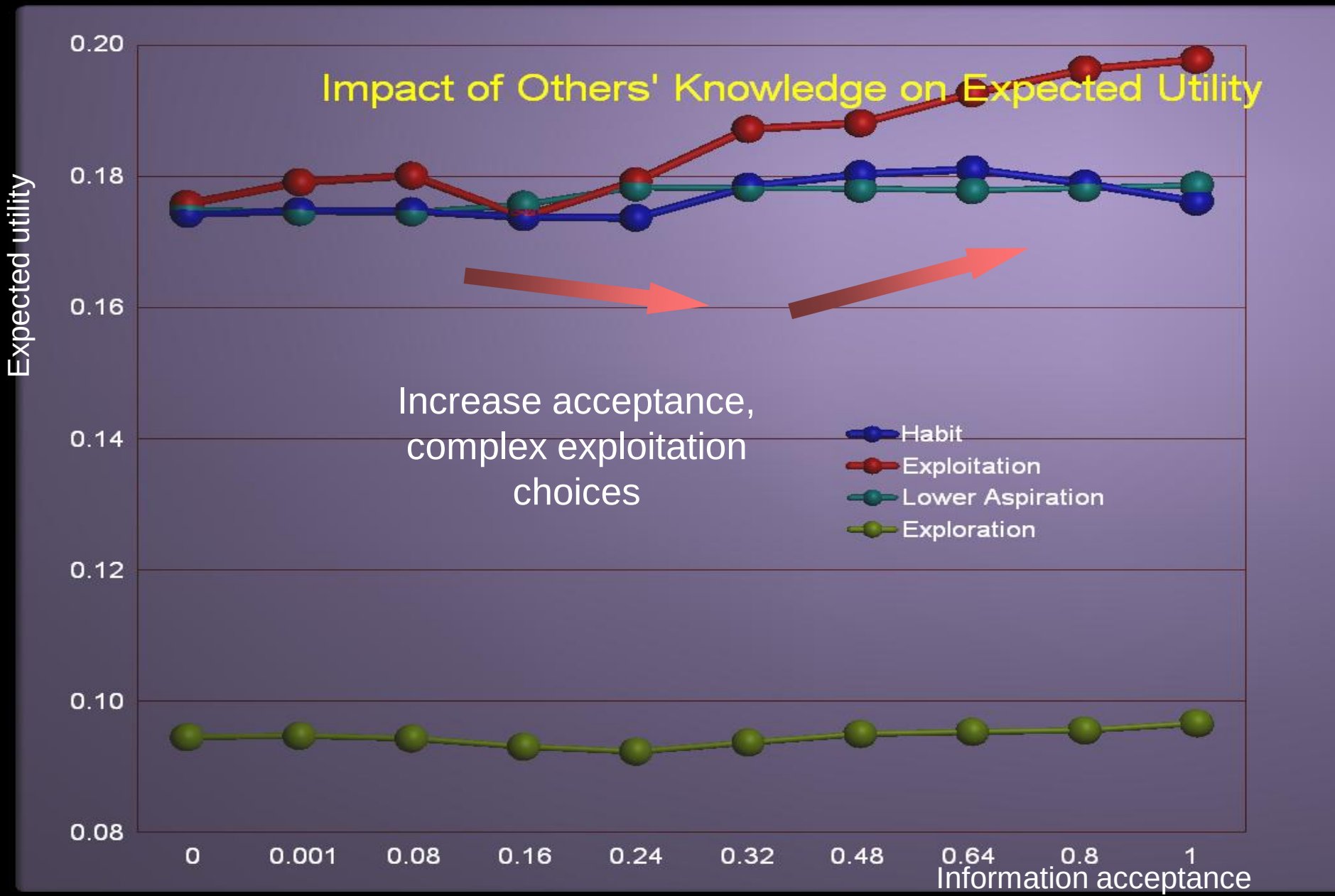

Impact of Comparing Aspiration on Choice Set
Number of alternatives
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Higher tolerance,
easily satisfied,
smaller set size
Set Size
Renewal Rate
0.001
0.01
0.03
0.06
0.09
0.1
0.2
Social deviation tolerance

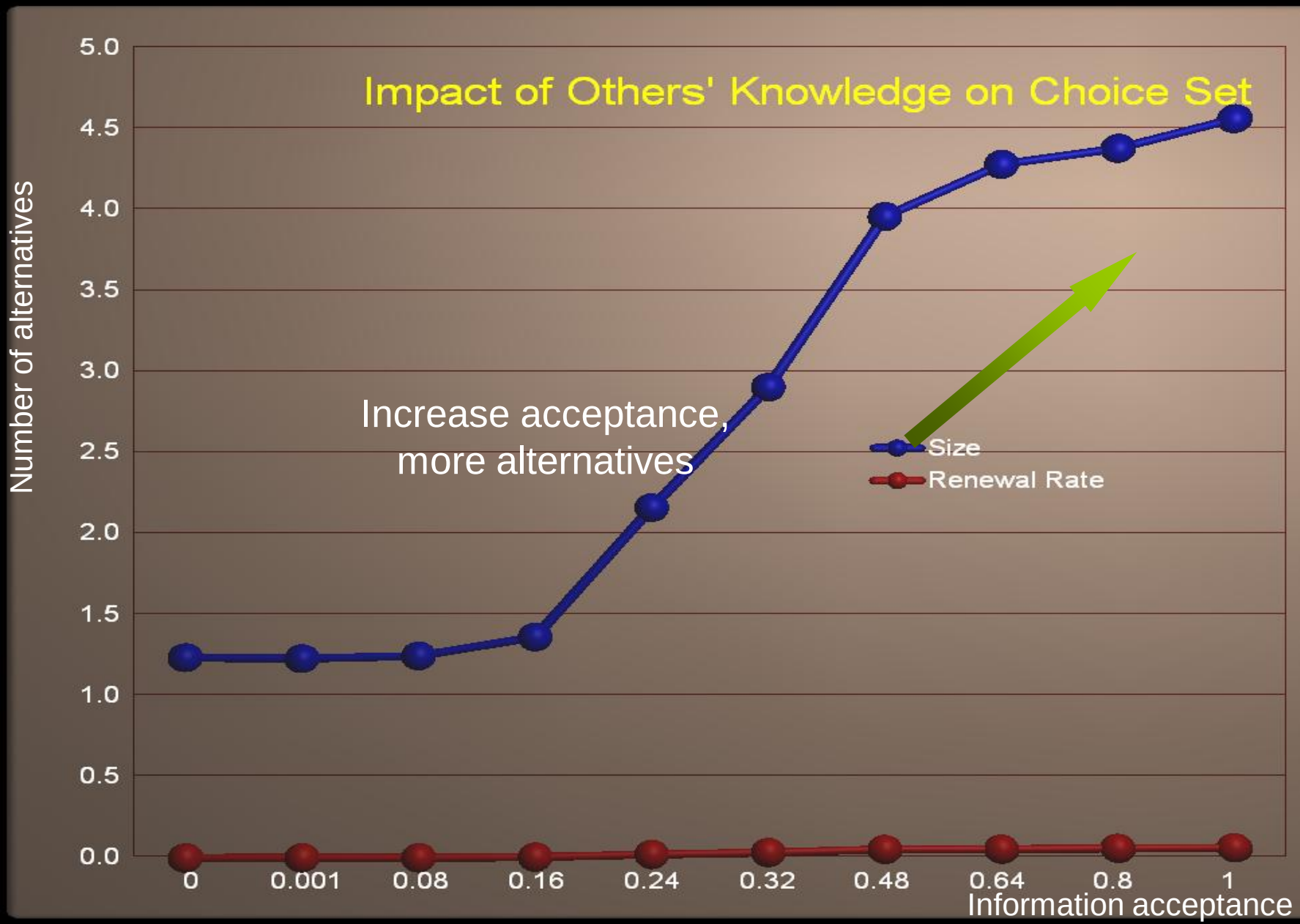

Impact of Comparing Aspiration on Expected Utility
Expected utility
0.170
0.168
0.166
0.164
0.162
0.160
0.158
Complex process,
more or less
stable pattern
Choice Average
Choice Set Average
0.001
0.01
0.03
0.06
0.09
0.1
0.2
Social deviation tolerance

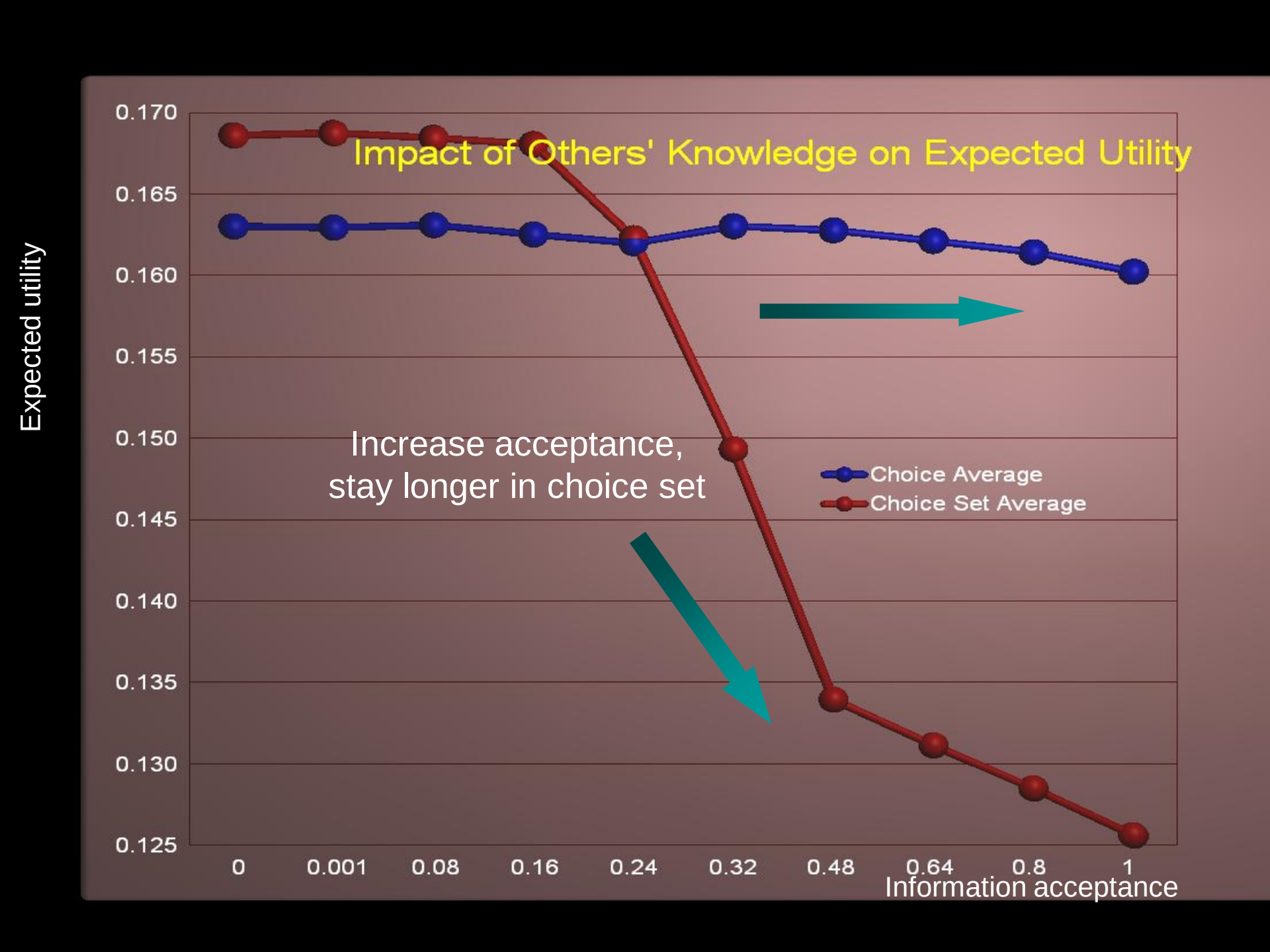
Properties

Impact of acceptance of others' information

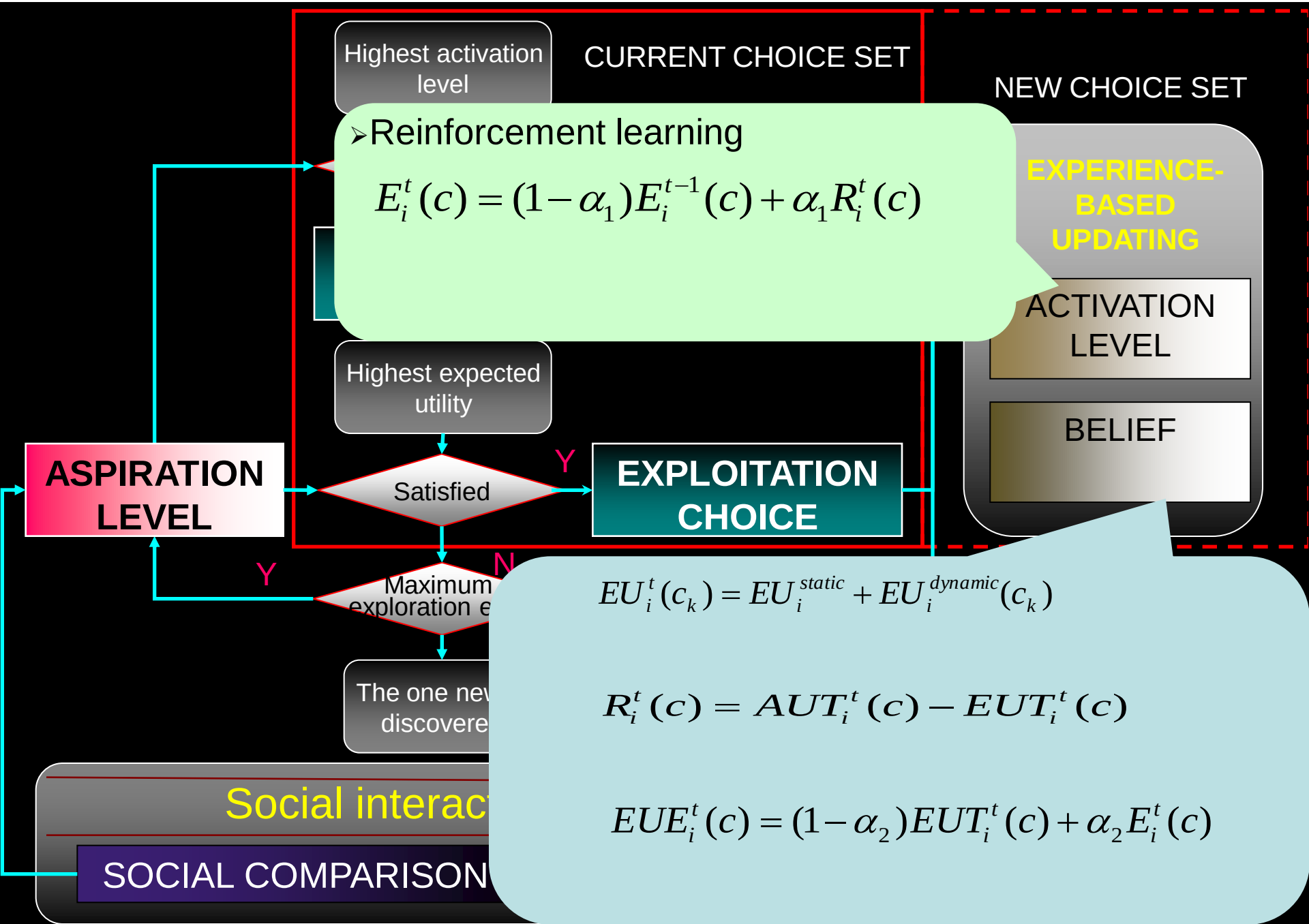

Impact of Others' Knowledge on Choice Mode
Number of choices
60.00
50.00
40.00
30.00
20.00
10.00
0.00
Habit
Exploitation
Lower Aspiration
Exploration
Increase acceptance,
less habit,
more conscious choice
0
0.001
0.08
0.16
0.24
0.32
0.48
0.64
0.8
1
Information acceptance


Impact of Others' Knowledge on Expected Utility
Expected utility
0.20
0.18
0.16
0.14
0.12
0.10
0.08
Increase acceptance, complex exploitation choices
Habit
Exploitation
Lower Aspiration
Exploration
0
0.001
0.08
0.16
0.24
0.32
0.48
0.64
0.8
1
Information acceptance

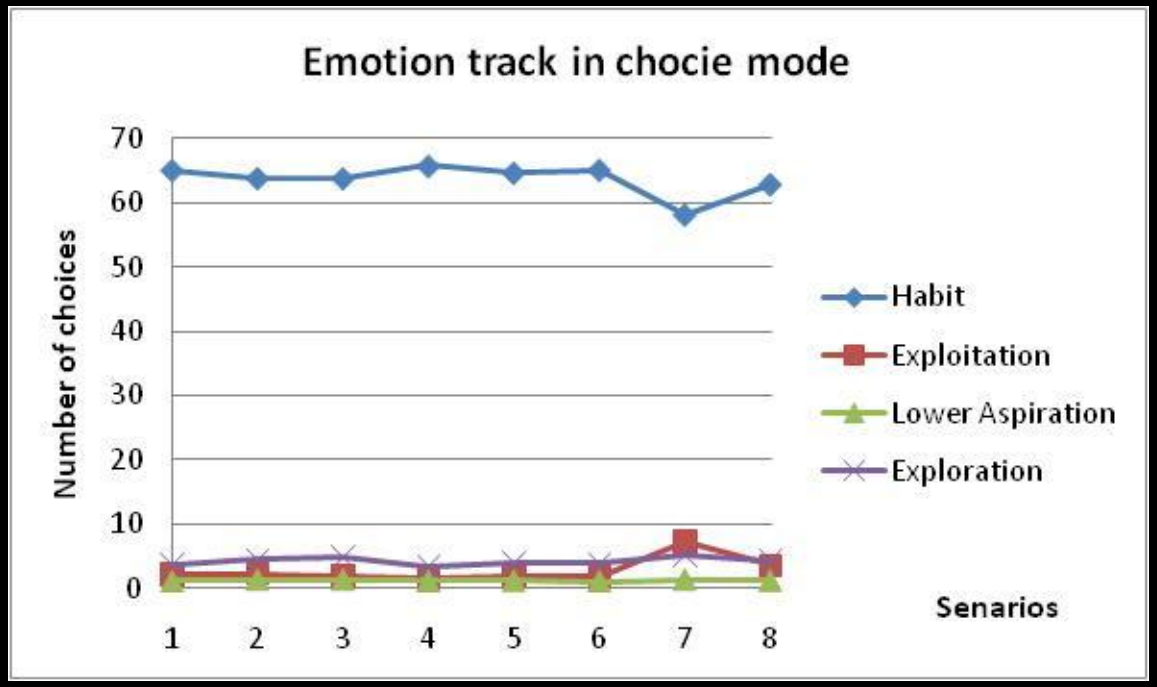

Impact of Others' Knowledge on Choice Set
Number of alternatives
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Increase acceptance,
more alternatives
Size
Renewal Rate
0
0.001
0.08
0.16
0.24
0.32
0.48
0.64
0.8
1
Information acceptance


Impact of Others' Knowledge on Expected Utility
Expected utility
0.170
0.165
0.160
0.155
0.150
0.145
0.140
0.135
0.130
0.125
0
0.001
0.08
0.16
0.24
0.32
0.48
0.64
0.8
1
Information acceptance
Increase acceptance,
stay longer in choice set
Choice Average
Choice Set Average

Process Model Affective Responses



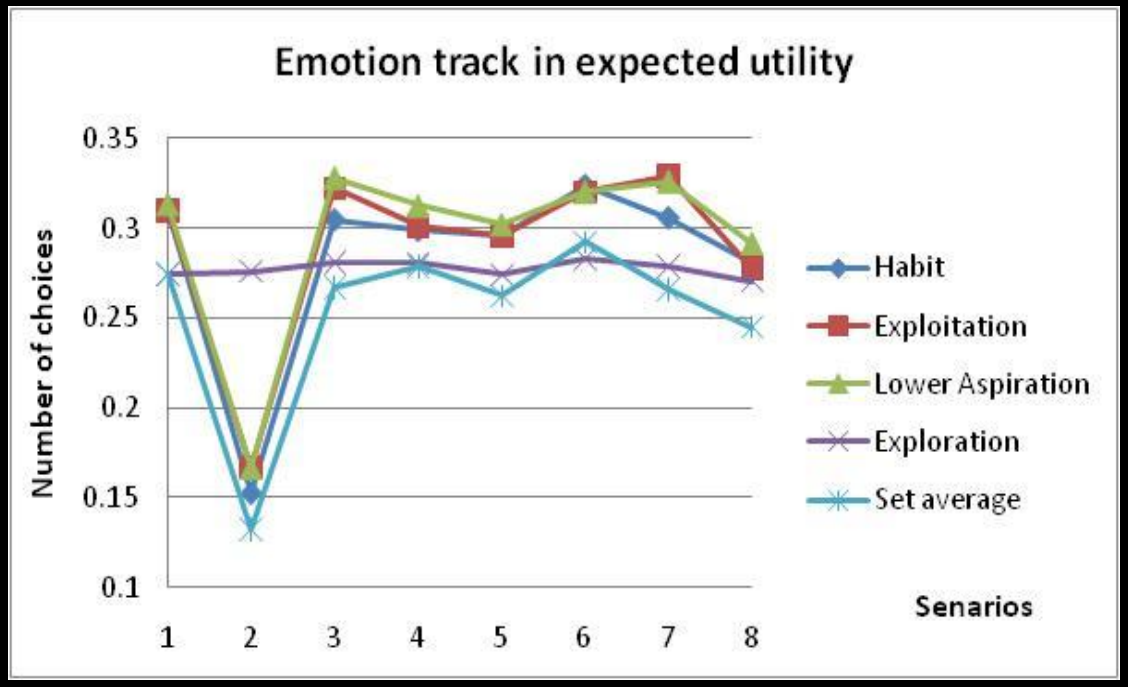
The impact of affective responses 1



Scenarios:

1. **Baseline case**
2. **Emotional decision**
3. **Recent emotions**
4. **Short memory**
5. **Negative surprises**
6. **Positive surprises**
7. **Higher fluctuate surprises**
8. **Negative mean surprises**

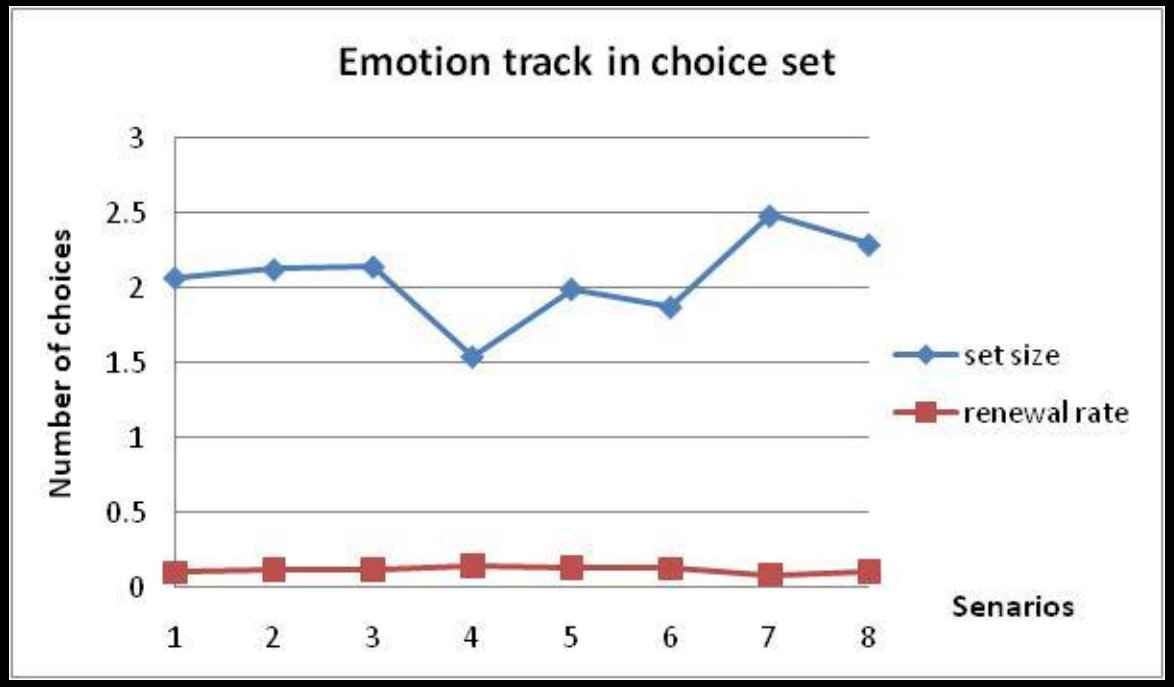
The impact of affective responses 2



Scenarios:

1. **Baseline case**
2. **Emotional decision**
3. **Recent emotions**
4. **Short memory**
5. **Negative surprises**
6. **Positive surprises**
7. **Higher fluctuate surprises**
8. **Negative mean surprises**

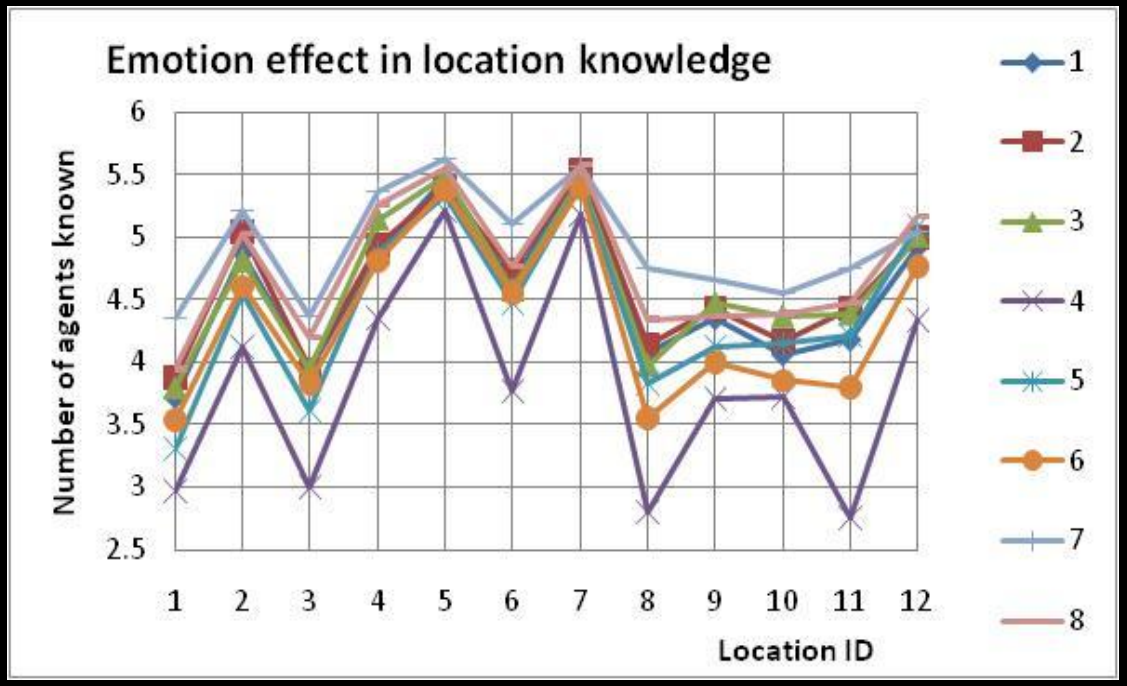
The impact of affective responses 1



Scenarios:

1. **Baseline case**
2. **Emotional decision**
3. **Recent emotions**
4. **Short memory**
5. **Negative surprises**
6. **Positive surprises**
7. **Higher fluctuate surprises**
8. **Negative mean surprises**

The impact of affective responses 1



Scenarios:

1. **Baseline case**
2. **Emotional decision**
3. **Recent emotions**
4. **Short memory**
5. **Negative surprises**
6. **Positive surprises**
7. **Higher fluctuate surprises**
8. **Negative mean surprises**

Conclusion and discussion

- System indicators respond in unique ways to proposed parameters
- Capable of distinguishing habitual, exploitation and exploration choices
- Competent in simulating habit formation and adaptation under uncertain environment (cognitive and affective response)

Thank you