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Action, Complexity and Cognition

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Possible Interpretations of 'Information'

1.) 'Information' as a message (syntax)

2.) 'Information' as the meaning of a message (semantic)

3.) 'Information' as the effect of a message (pragmatic)

4.) 'Information' as a process

5.) 'Information' as knowledge

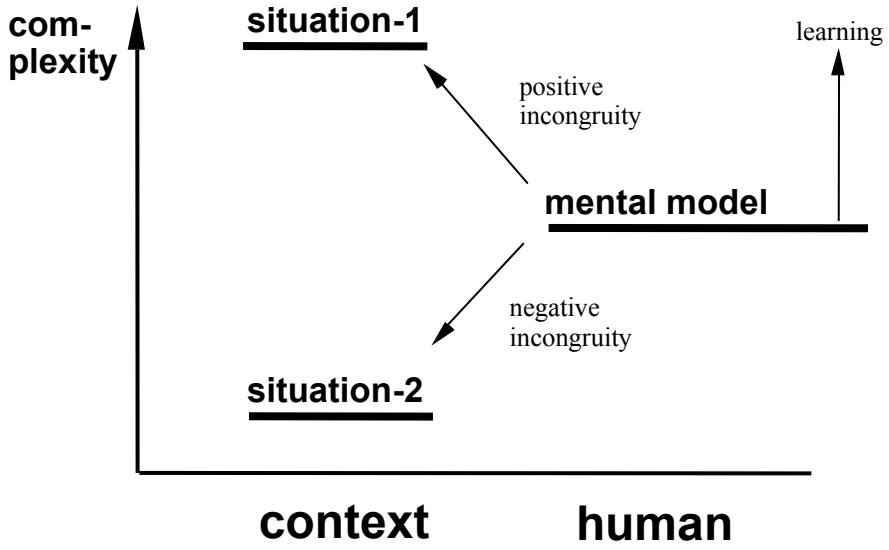
6.) 'Information' as an entity of the world

Ref: Folberth, O. & Hackl, C. (1986, eds.) Der Informationsbegriff in Technik und Wissenschaft. München: Oldenbourg.

“Information” for Learning Systems

before reception	after reception	Author
dof of the decision	content of the decision	HARTLEY 1928
uncertainty	certainty	SHANNON 1949
uncertainty	information	BRILLOUIN 1964
potential information	actual information	ZUCKER 1974
entropy	amount of information	TOPSØE 1974

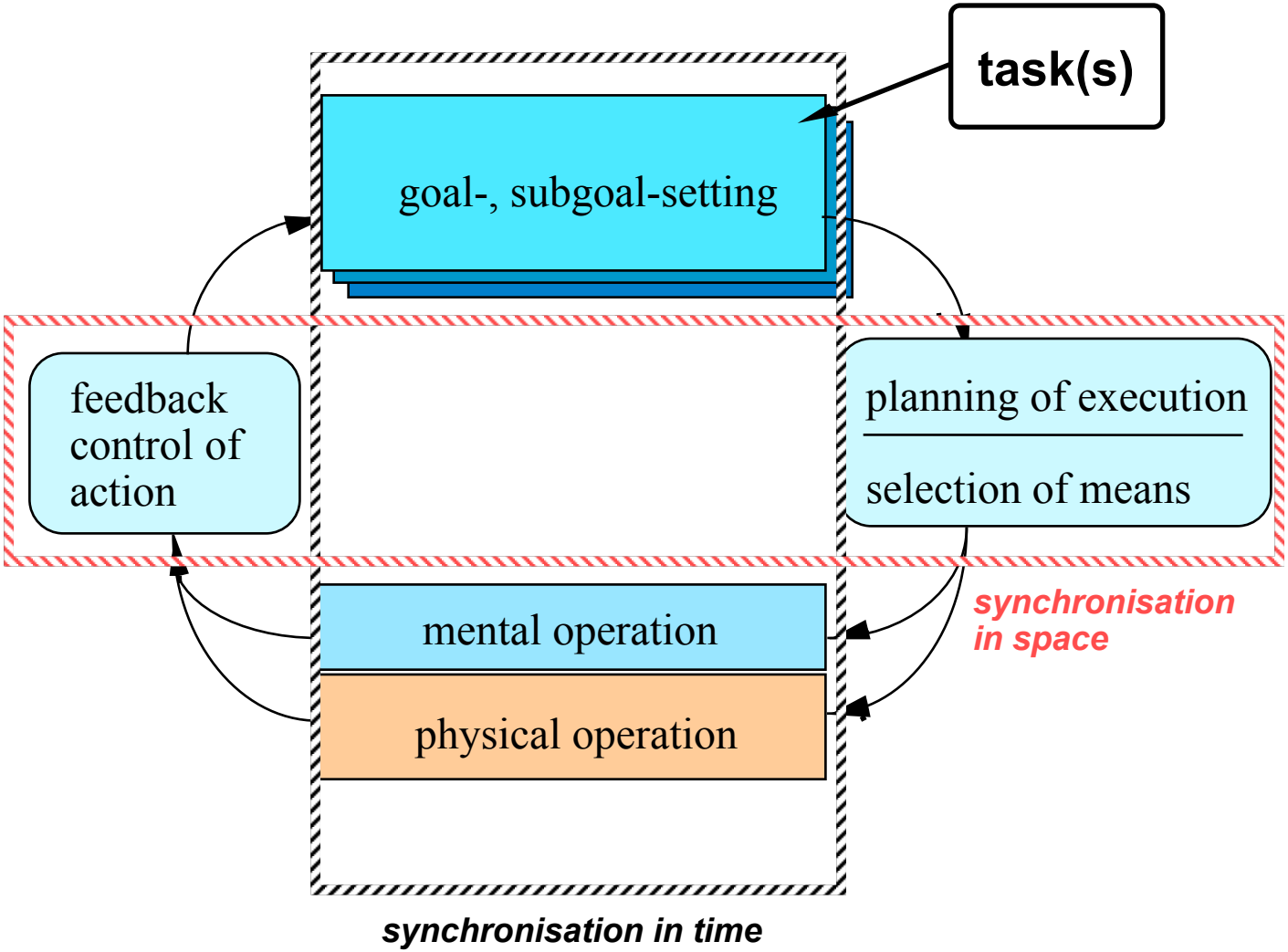
Incongruity and Learning



$$\text{Incongruity} = \text{Complexity}_{\text{context}} - \text{Complexity}_{\text{human}}$$

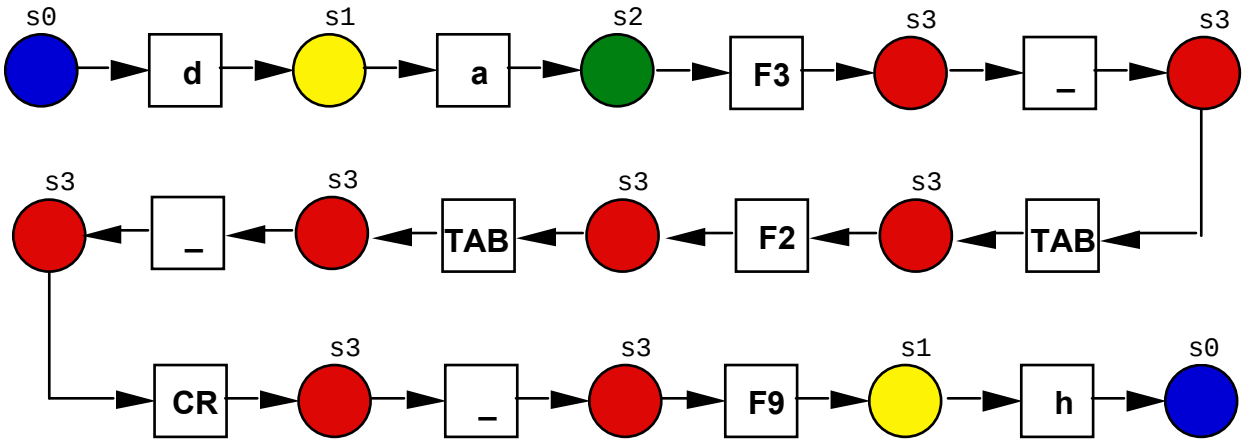
Ref: Rauterberg, M. (1995). About a framework for information and information processing of learning systems. In: E. Falkenberg, W. Hesse & A. Olive (eds.), Information System Concepts--Towards a consolidation of views (IFIP Working Group 8.1, pp. 54-69). London: Chapman&Hall.

The Complete Action Cycle



The Idea

Any human task solving process can be described in a finite state-transition chain, if the task can be described in an ‘action space’, specified by a **finite** set of states ( ) and transitions [ ].



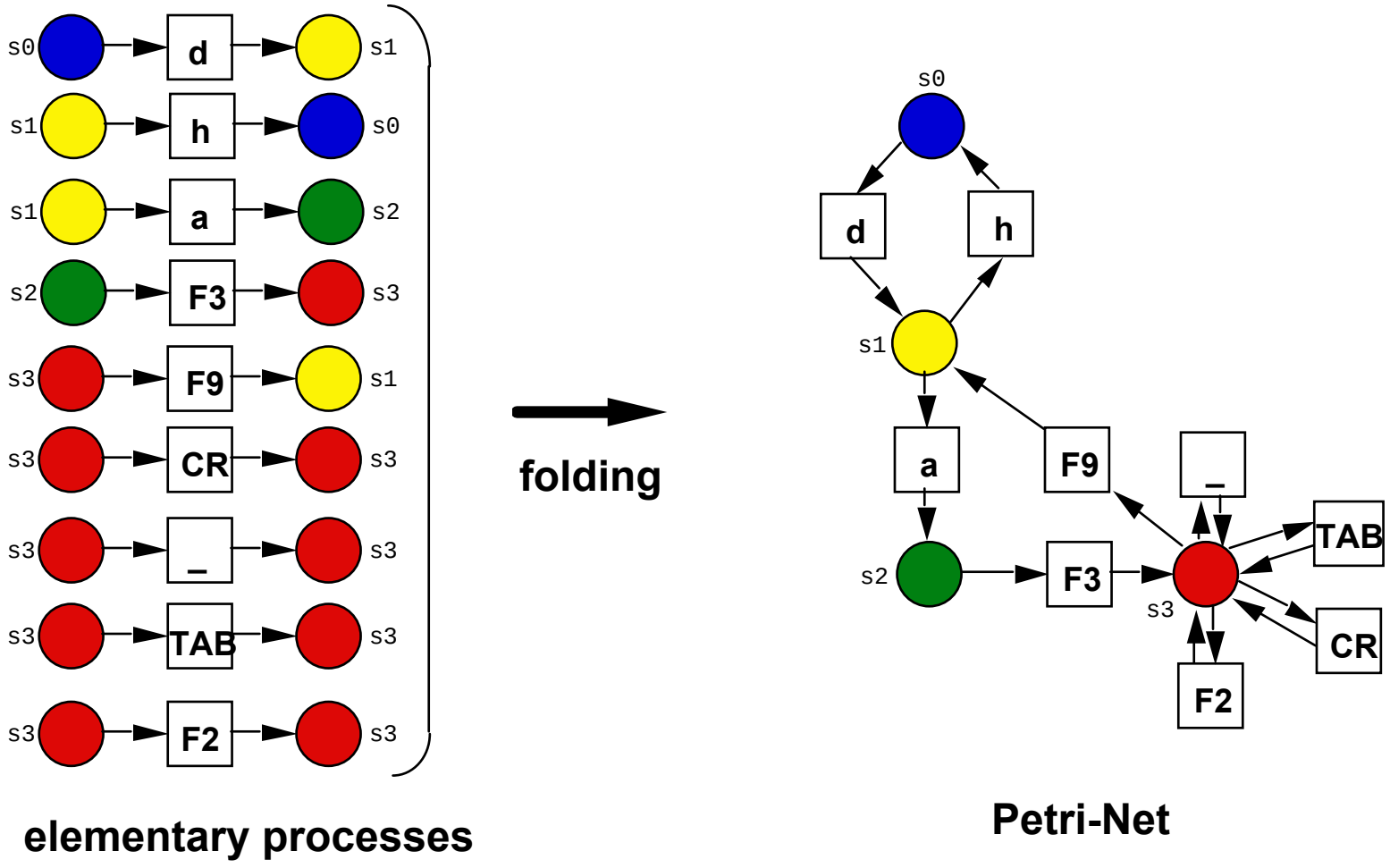
State description:

s0 : main menu
s1 : modul "data"
s2 : routine "browse"
s3 : "wrong input" state

Action description:

_ : ascii key "BLANK"
a : ascii key "a"
d : ascii key "d"
h : ascii key "h"
CR: carriage return
F2: function key "2"
F9: function key "9"
TAB:tabulator key

The Folding Operation in Petri Nets



elementary processes

Petri-Net

Task Description

In the experiment all 12 users had to play the role of a camping place manager. This manager uses a database system with a data base consisting of three data files: PLACE, GROUP, and ADDRESS. All users had to solve the following four different tasks operating the database system:

Task 1: "How many data records are in the file ADDRESS, in the file PLACE, and in the file GROUP? Find out, please."

The user has to activate a specific menu option ("Datafile" in module "Info" of the menu interface) and to read the file size (solutions: PLACE = 17 data records, GROUP = 27 data records, ADDRESS = 280 data records).

Task 2: "Delete only the last data record of the file ADDRESS, the file PLACE, and the file GROUP (sorted by the attribute 'namekey')."

The user has to open (sorted according to the given attribute), select and delete the last data record (file: PLACE, GROUP, ADDRESS).

Task 3: "Search and select the data record with the namekey 'D..8000C O M' in the file ADDRESS, and show the content of all attributes of this data record on the screen. Correct this data record for the following attributes: State: Germany, Place number: 07. Remarks: Database system dealer can give a demonstration."

The user must select a certain data record (file: ADDRESS), update the data record with regard to the three attributes: State, Place number, Remarks.

Task 4: "Define a filter for the file PLACE with the following condition: all holidaymakers arrived on date 02/07/87. Apply this filter to the file PLACE, and show the content of all selected data records in the mask browsing mode on the screen."

The user must define a filter for the attribute "arrival date", apply the filter to the data file PLACE, and display the content of each data record found on the screen.

System Description

The dialog system was the relational data base system ADIMENS version 2.21 with a character oriented user interface (CUI) running on standard IBM PC's with standard keyboard.

The whole dialog structure is strictly hierarchical organized with three levels:

(1) the main menu has 7 dialog operations (ordinary ASCII characters chosen from a menu) to go down to 7 different modules, and 5 function keys with specific semantics;

(2) at the module level each module has exactly 4 different dialog operations to change to routines and on average 4.1 (±1.7; range: 0-5) function keys with specific semantics;

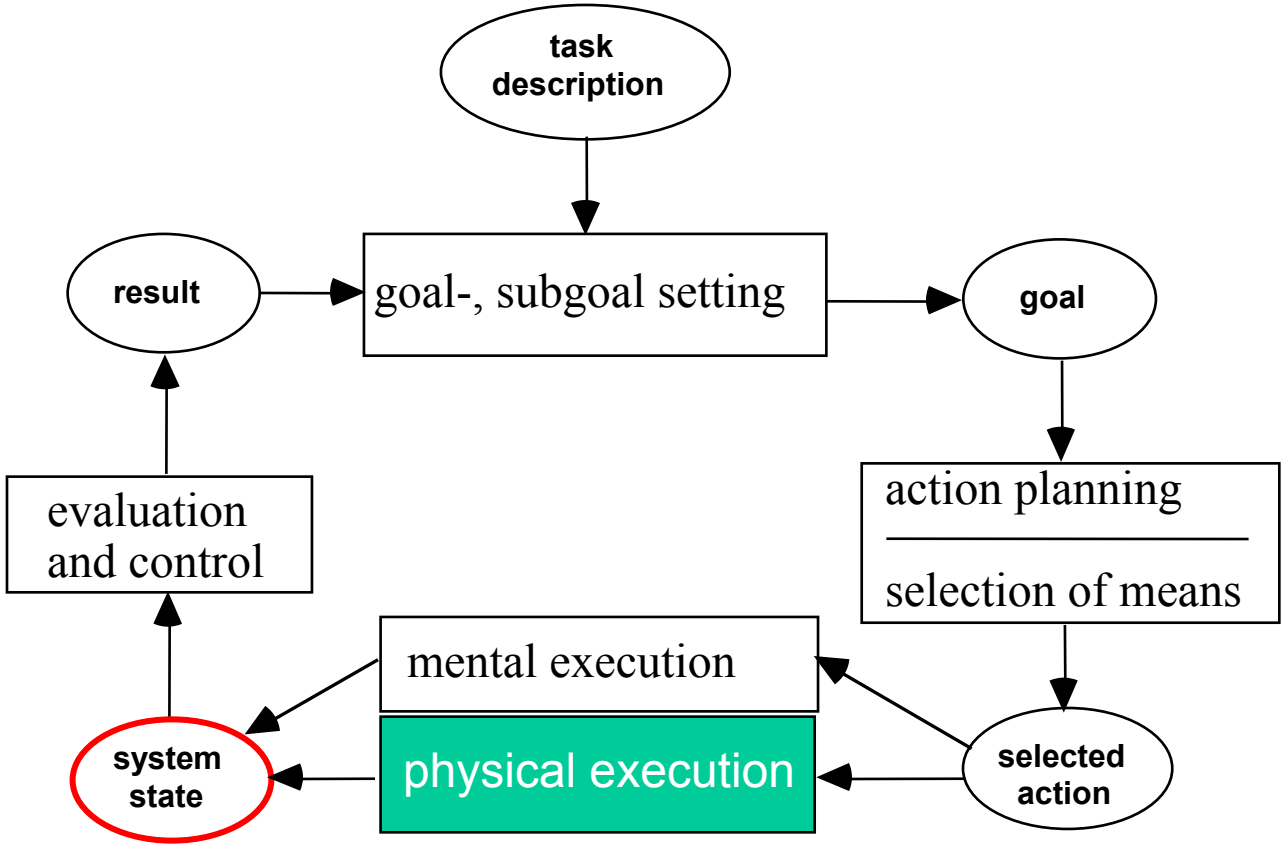
(3) at the routine level the user has only on average 3.7 (±2.9; range: 0-10) different function keys to control the dialog (additionally all ASCII keys and the 4 cursor keys are usable).

The number of all ordinary dialog contexts (main menu, modules, routines) is 1+7*4=29.

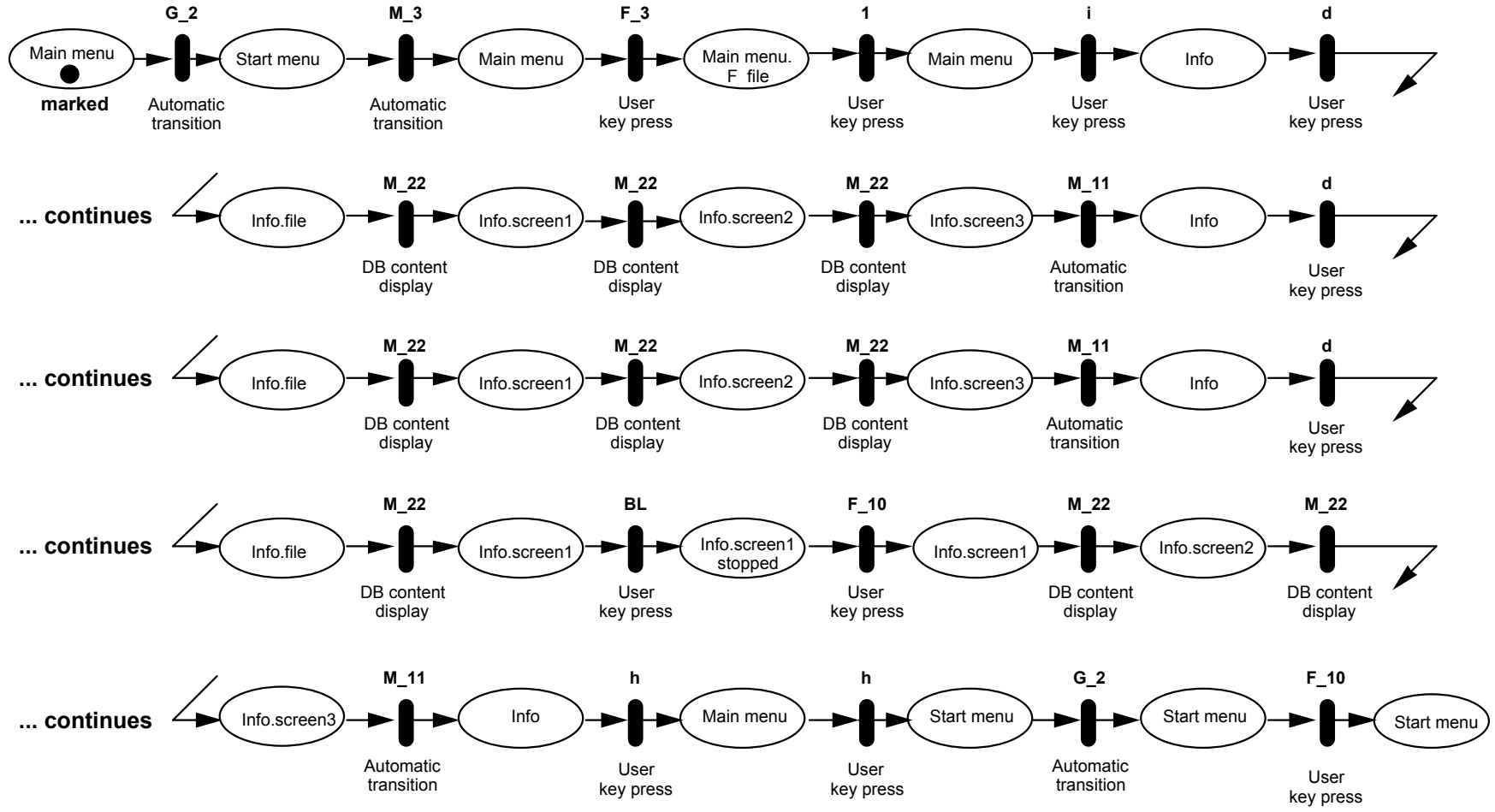
But to describe the complete dialog structure with all help, error and additional dialog states we need at least 144 different system states.

To change from one state to the other the system offers overall 358 different dialog operations (transitions).

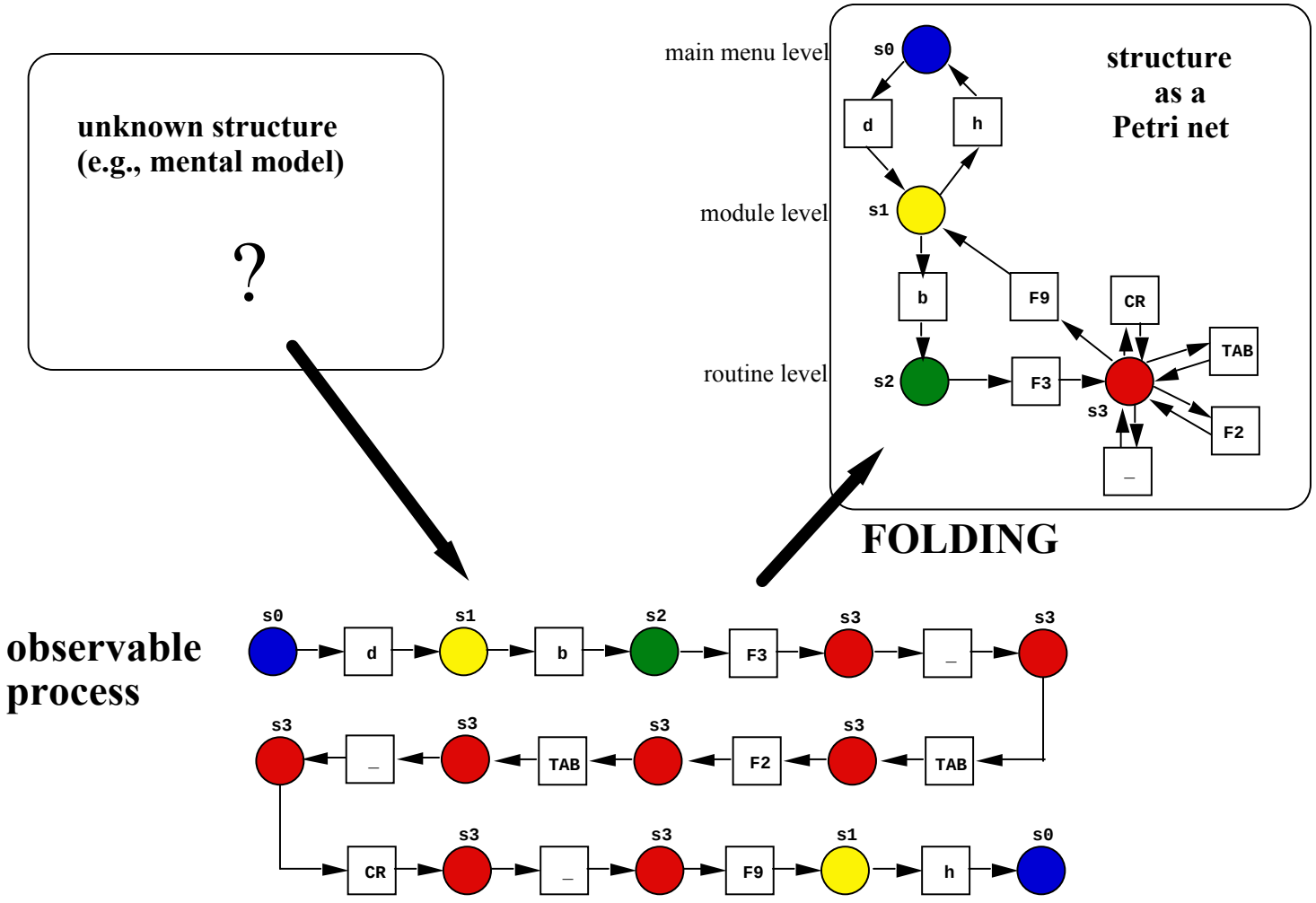
Observable Data



Example of a task solving process



How to Extract the User's Mental Model?



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How to measure complexity?

In Computer Science...

- algorithmic information (Solomonoff-Kolmogorov-Chaitin)
- computational universality
- computational time/space
- according McCabe in graph theory

In Physics...

- thermodynamics potentials
- long-range order
- long-range mutual information
- self-similar structures
- thermodynamic depth
- logical depth

In Psychology...

- properties of objects (e.g. valence)
- properties of attributes (e.g. ordinality)
- properties of cognitive structure (e.g. centrality)

Net Complexity Metrics

Stevens, Myers and Constantine (1974):

$$C_{state} = S$$

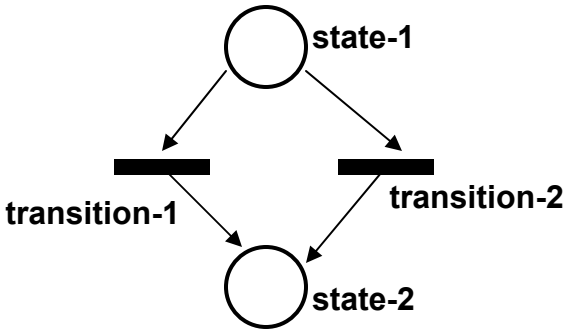
$$C_{fan} = T / S$$

McCabe (1976): $C_{cycle} = T - S + P$ [with P=1]

Kornwachs (1987): $C_{density} = T / (S*(S-1))$

T = number of transitions
S = number of states

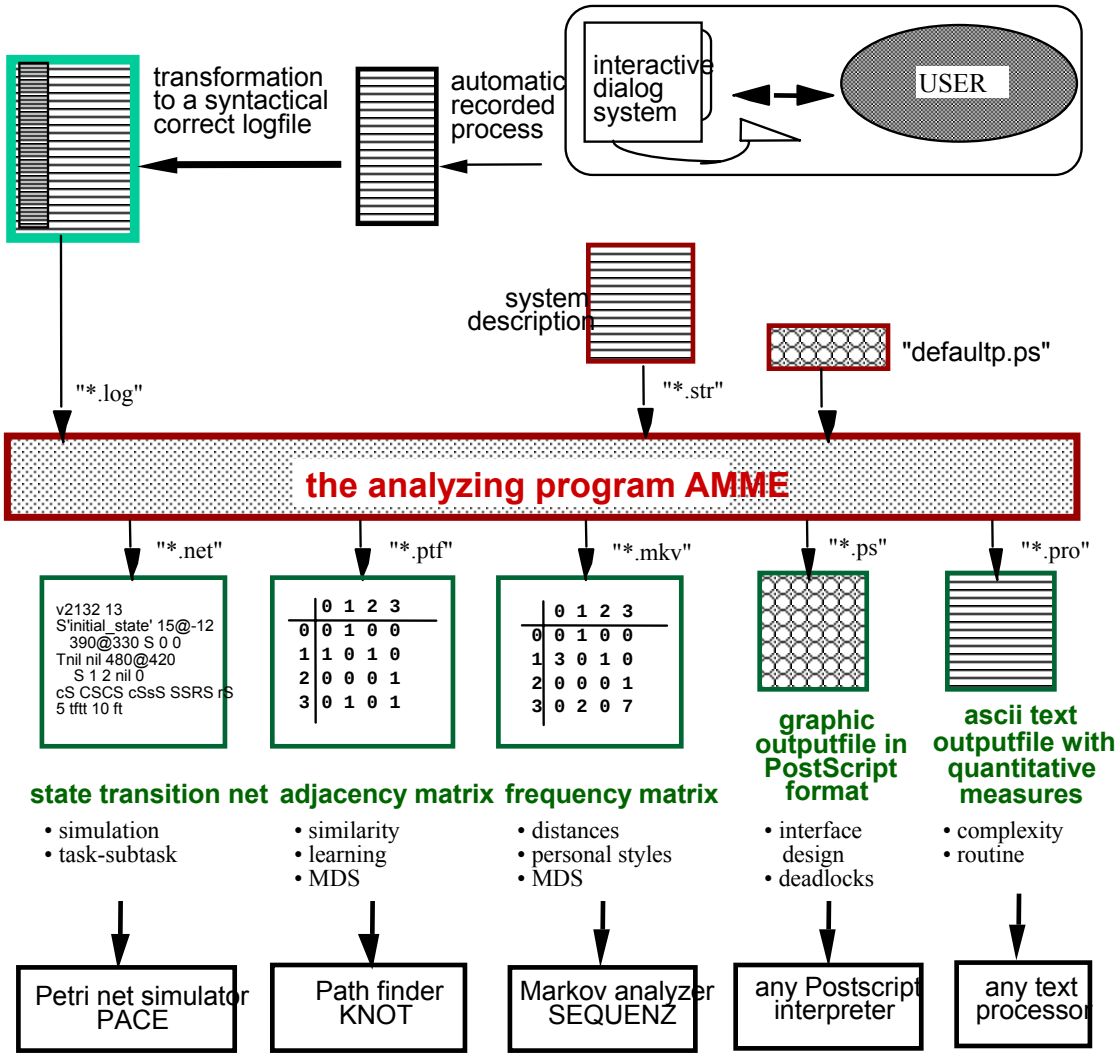
Simple Petri Net:



Validation study:
C_{cycle} from McCabe outperforms all other metrics!

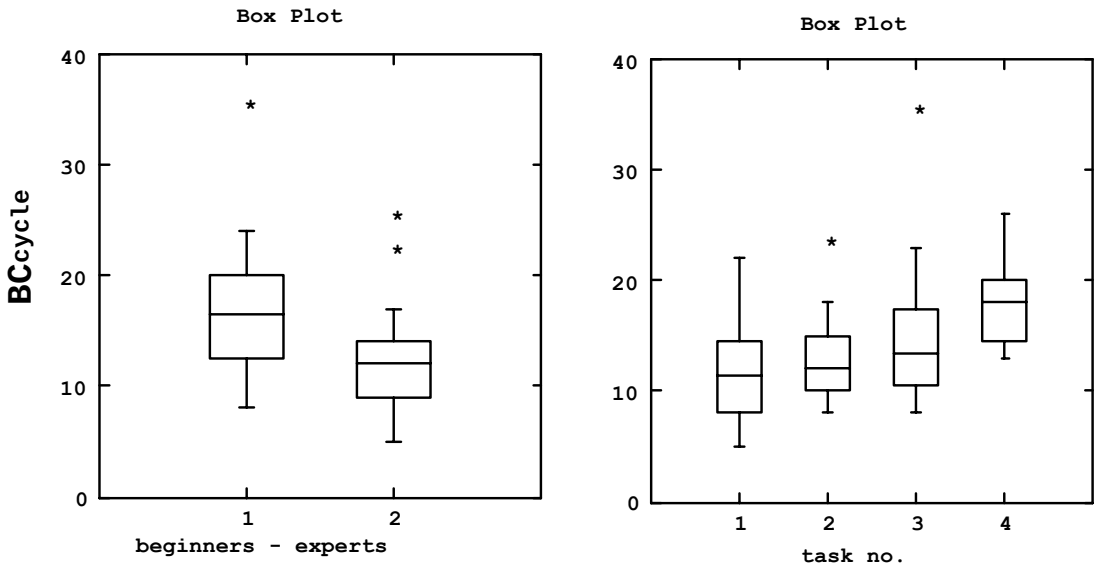
Ref: Rauterberg, M. (1992). A method of a quantitative measurement of cognitive complexity. In: G. van der Veer, M. Tauber, S. Bagnara & M. Antalovits (eds.), Human-Computer Interaction: Tasks and Organisation--ECCE'92 (pp. 295-307). Roma: CUD.

The AMME Program Structure



Behavioral Complexity (BC) àla McCabe (1976)

$$BC_{cycle} = T - S + 1$$



SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
experience	275.521	1	275.521	10.337	0.003
tasks	259.563	3	86.521	3.246	0.032
exp. x tasks	25.729	3	8.576	0.322	0.810
ERROR	1066.167	40	26.654		

Experiment:

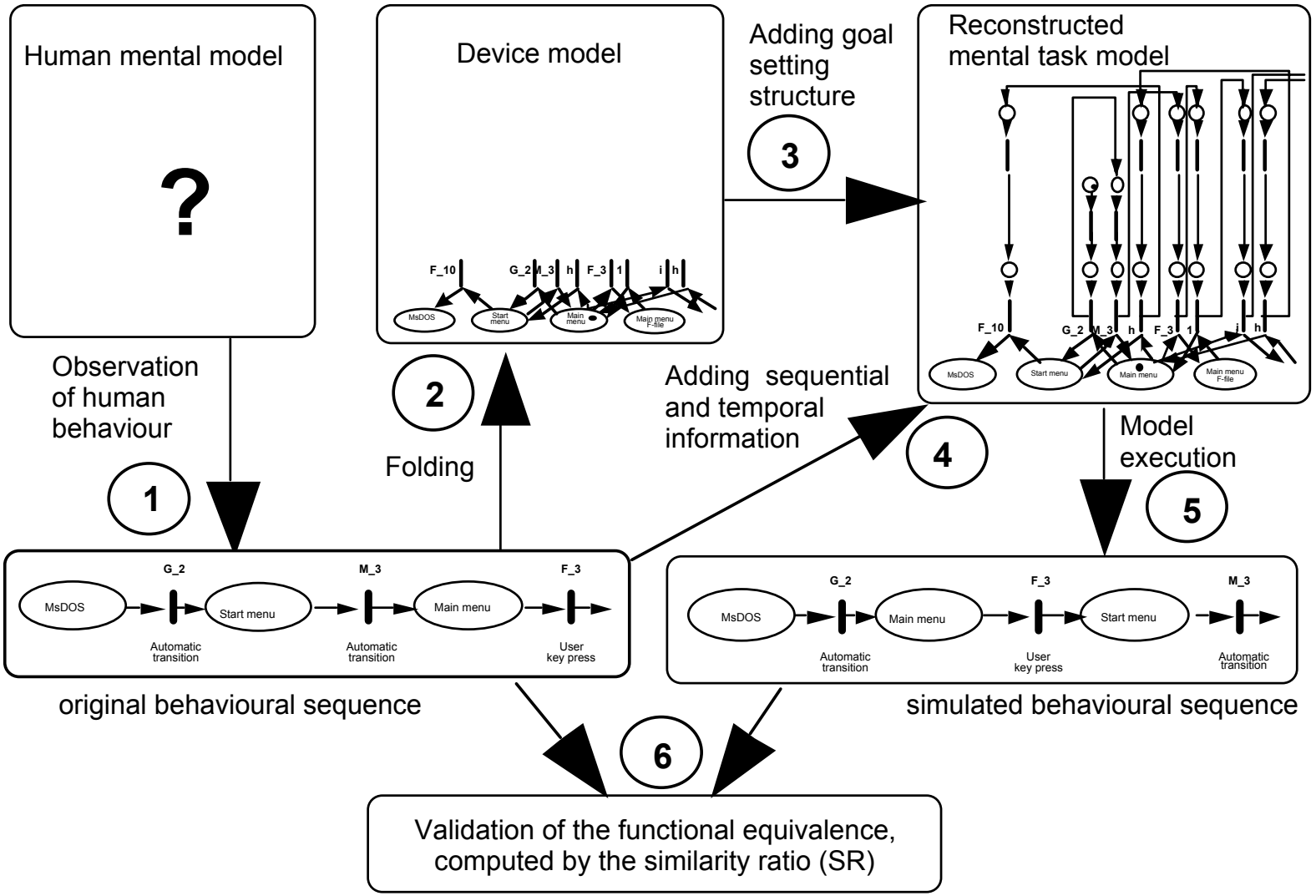
N=6 novices; N=6 experts

4 tasks with a database

Metric $BC=C_{cycle}$

Ref: Rauterberg, M. (1993). AMME: an Automatic Mental Model Evaluation to analyze user behaviour traced in a finite, discrete state space. *Ergonomics,* vol. 36(11), pp. 1369-1380.

Validation of extracted Mental Models



The Similarity Ratio SR

$$SR = \left[1 - \left\{ \sum_{t=1}^{N_{sim}} \left| R_{org,t} - R_{sim,t} \right| + \sum_{N_{sim+1}}^{N_{org}} \max\left(R_{org}\right) \right\} \Big/ N_{org}^2 \right] * 100\%$$

Legend: **R** is the absolute rank position in the **orig**inal or **sim**ulated process

Table 1. The model complexity (MC) and similarity ratios (SR) of model-1, -2, -3, and -4.

	Model-1	Model-2	Model-3	Model-4
MC: absolute value	6	8	13	13
SR: mean	43 %	57 %	86 %	95 %
SR: standard deviation	± 33 %	± 23 %	± 12 %	± 1 %
SR: minimum … maximum	10% … 83%	32% … 93%	68% … 94%	94% … 96%
number of simulated sequences	11	12	8	8

Ref: Rauterberg, M. (1995). From novice to expert decision behaviour: a qualitative modelling approach with Petri nets. In: Y. Anzai, K. Ogawa & H. Mori (eds.), Symbiosis of Human and Artifact: Human and Social Aspects of Human-Computer Interaction--HCI'95 (Advances in Human Factors/Ergonomics, Vol. 20B, pp. 449-454). Amsterdam: Elsevier.

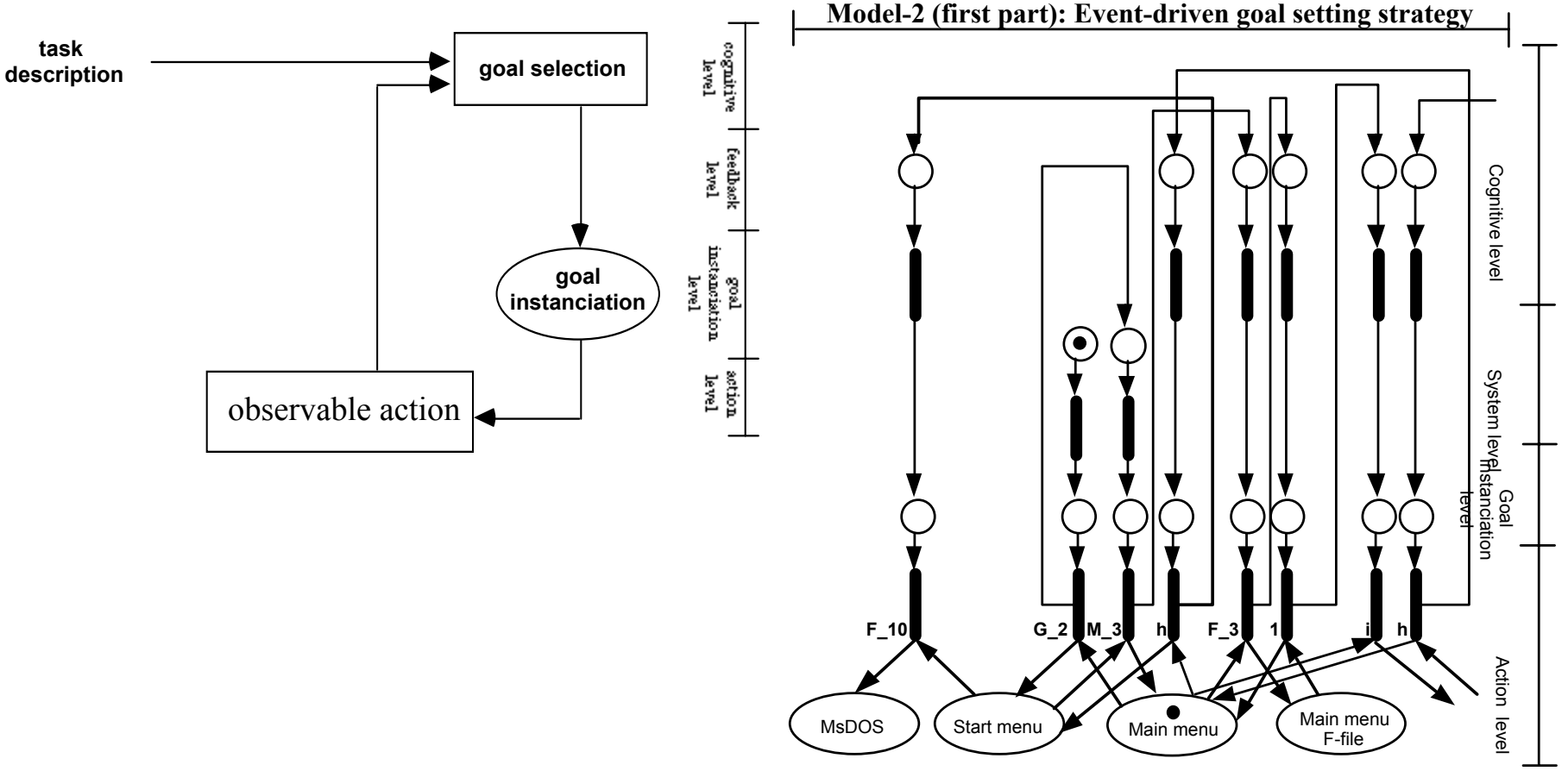
Simulation Results: Model-1

	original	Simulated logfiles with Model-1										
SR →	43%	40%	77%	76%	10%	10%	79%	67%	10%	10%	10%	83%
	d	d	d	d	d	d	d	d	d	d	d	d
	a	a	a	a	h	h	a	a	h	h	h	a
	F3	F3	F3	F3			F3	F3				F3
	space	TAB	TAB	space			TAB	space				F9
	space	F9	space	CR			CR	space				a
	TAB	h	F2	space			CR	CR				F3
	F2		F2	F9			TAB	space				TAB
	TAB		CR	a			space	F9				CR
	CR		F9	F3			F2	h				space
	space		h	TAB			F9					space
	F9			F9			h					F9
	h			a								h
				...								

Simulation Results: Model-4

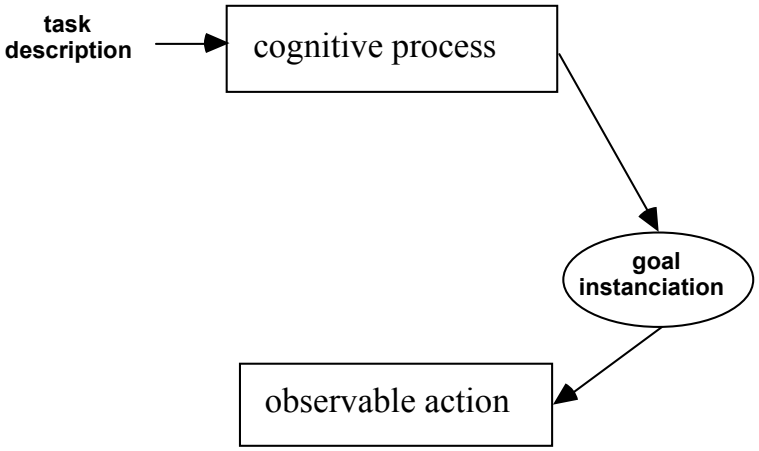
original	Simulated logfiles with Model-4											
SR → 95%	94%	94%	96%	96%	94%	96%	94%	94%	94%	94%	94%	96%
d	d	d	d	d	d	d	d	d	d	d	d	d
a	a	a	a	a	a	a	a	a	a	a	a	a
F3	F3	F3	F3	F3	F3	F3	F3	F3	F3	F3	F3	F3
space	space	space	space	space	space	space	space	space	space	space	space	space
space	space	TAB	space	space	TAB	space	TAB	space	TAB	TAB	TAB	space
TAB	space	space	TAB	TAB	space	TAB	space	space	space	space	space	TAB
F2	TAB	TAB	TAB	space	TAB	TAB	TAB	TAB	space	space	TAB	space
TAB	TAB	space	space	TAB	space	space	space	TAB	TAB	TAB	space	TAB
CR	F2	F2	F2	F2	F2	F2	F2	F2	F2	F2	F2	F2
space	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR
F9	F9	F9	F9	F9	F9	F9	F9	F9	F9	F9	F9	F9
h	h	h	h	h	h	h	h	h	h	h	h	h

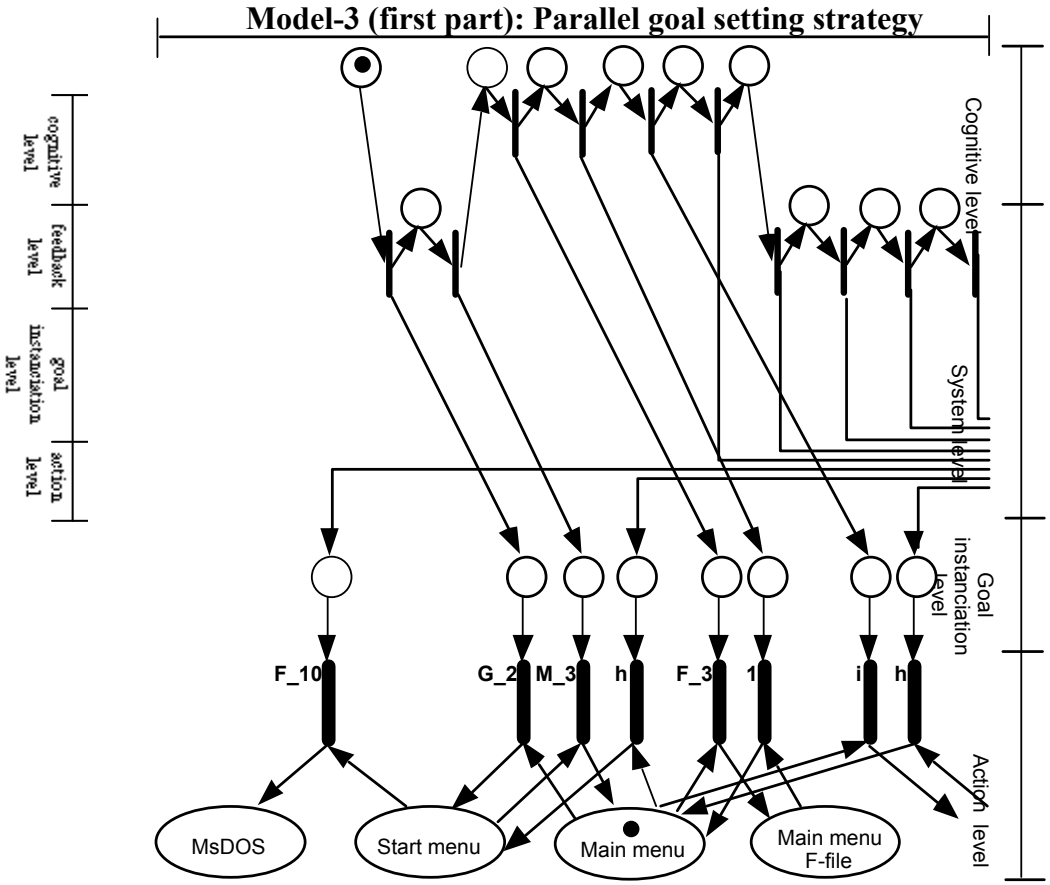
Model-2: event-driven goal setting



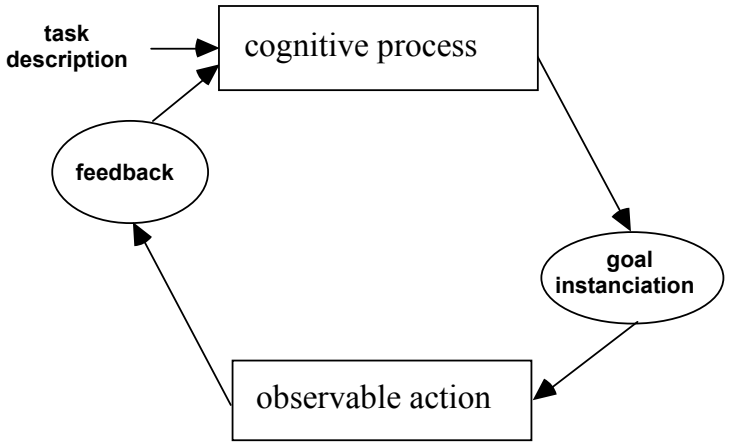
Ref: Rauterberg, M., Fjeld, M. & Schluep S. (1997). Parallel or event-driven goal setting mechanism in Petri net based models of expert decision behaviour. In: S. Bagnara, E. Hollnagel, M. Mariani & L. Norros (eds.), Time and Space in Process Control--CSAPC'97 (Sixth European Conference on Cognitive Science Approaches to Process Control, pp. 98-102). Roma: CNR.

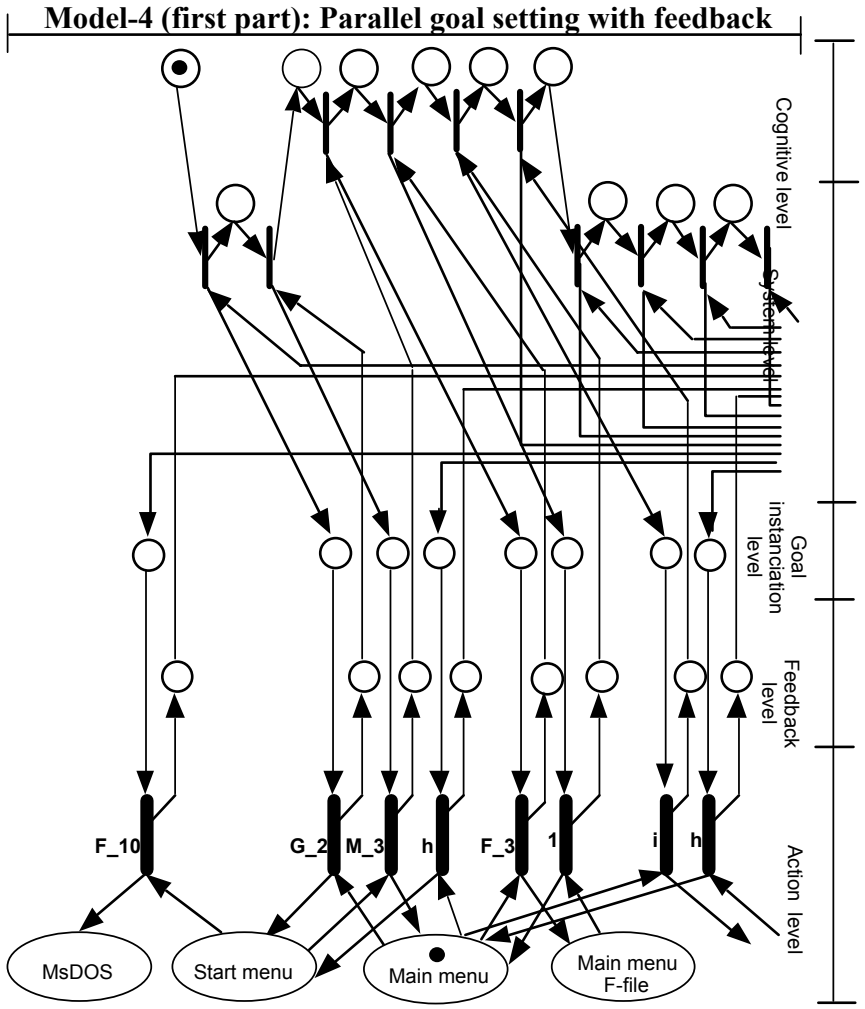
Model-3: parallel goal setting without feedback





Model-4: parallel goal setting with feedback





The Similarity Ratio SR

$$SR = \left[1 - \left\{ \sum_{t=1}^{N_{sim}} \left| R_{org,t} - R_{sim,t} \right| + \sum_{N_{sim+1}}^{N_{org}} \max\left(R_{org}\right) \right\} \Big/ N_{org}^2 \right] * 100\%$$

Legend: **R** is the absolute rank position in the **orig**inal or **sim**ulated process

Table 1: The model complexity (C_{cycle}) and similarity ratio (SR) of the modeling approaches-1, -2, -3 and -4 [std:=standard deviation].

	modeling approach no. 1	modeling approach no. 2	modeling approach no. 3	modeling approach no. 4
C_{cycle}: (mean ± std):	13 ± 5	43 ± 17	57 ± 25	101 ± 43
C_{cycle}: (min…max.):	6…18	22…68	30…97	55…170
SR (mean % ± std):	41 ± 28	66 ± 21	88 ± 11	100 ± 0
SR (min…max. %):	3…79	36…98	67…100	100…100
# simulated sequences	5*6=30	5*6=30	5*6=30	5*6=30

Overview over different measures

Measuring Complexity

C_{cycle} = #T – #S+P with #S =< #T and P=1

C'_{cycle} = #F–(#T + #S)+P with #S > #T and P=1

Measuring 'Routinization'

#R = #AT / #DT

Measuring 'Personality Styles'

#MTT = #TST / #DS

T = number of transitions
S = number of states
F = number of connectors
TST = task solving time
AT = all used transitions
DT = all different transitions
DS = all different states

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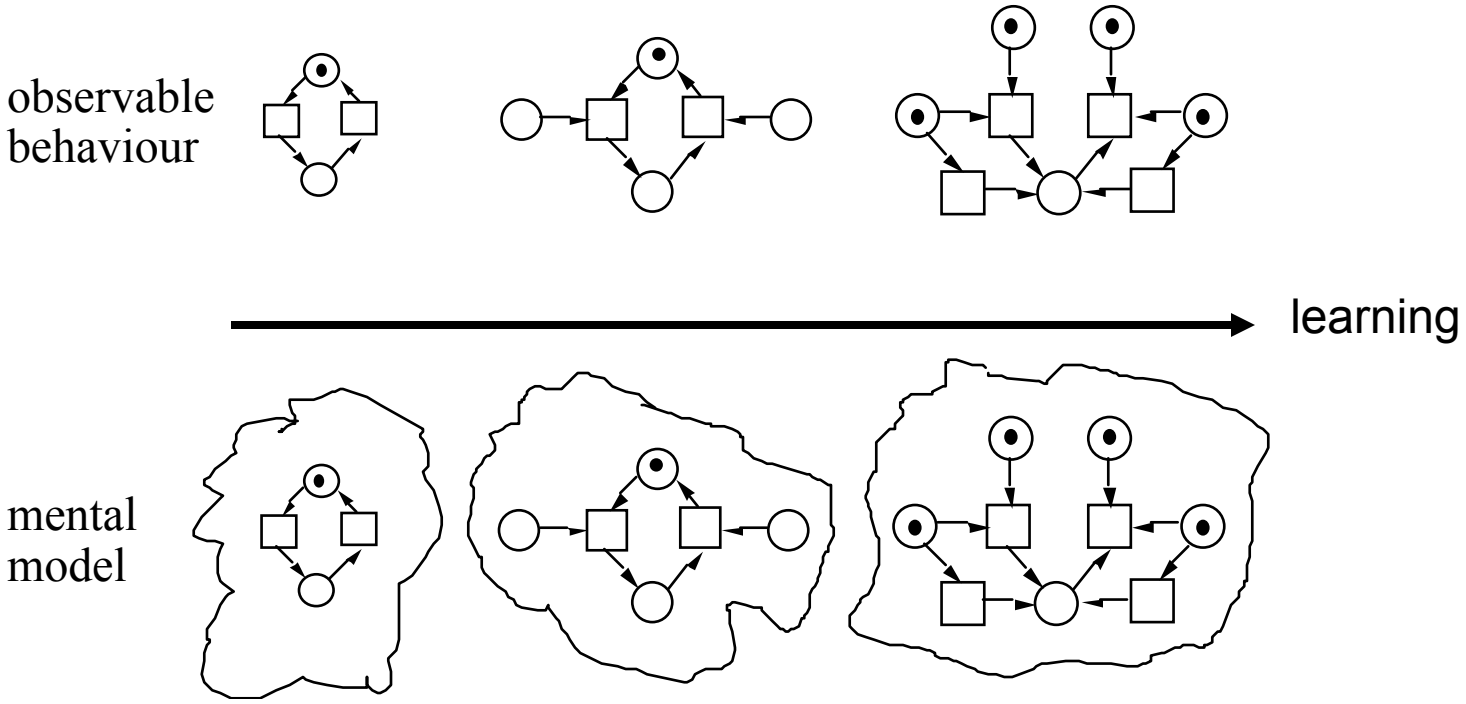
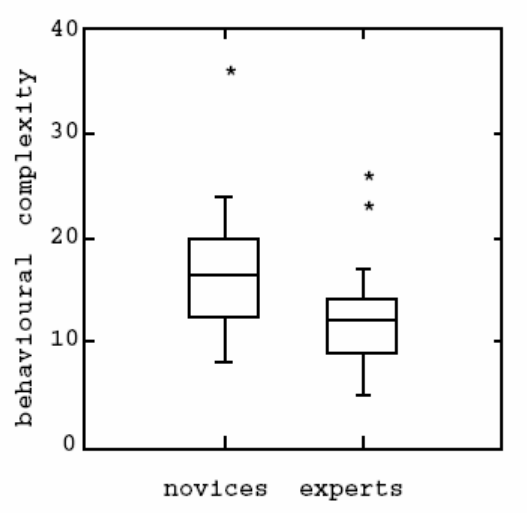
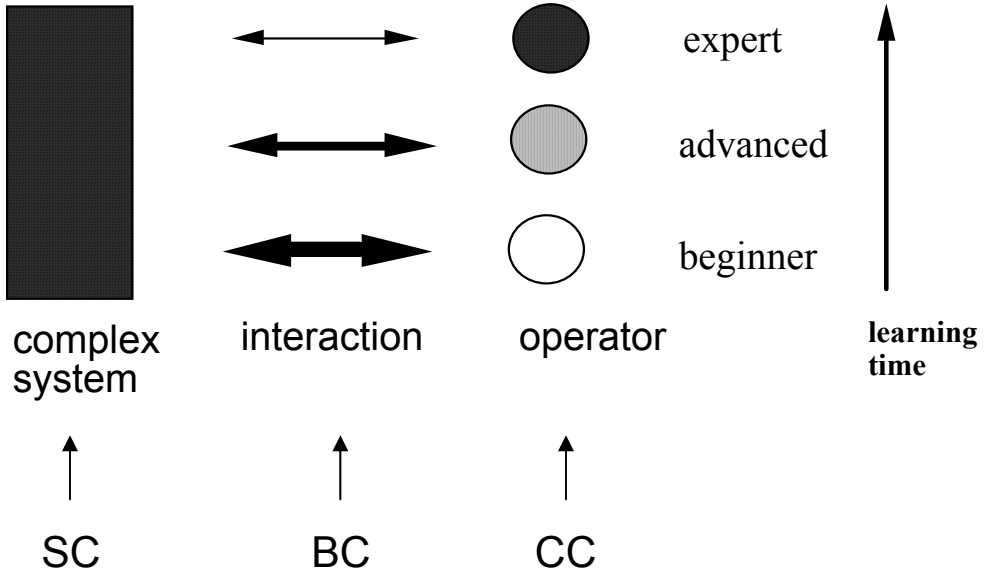
The common AI assumption



Ref: Rauterberg, M. (1996). About faults, errors, and other dangerous things. In: C. Ntuen & E. Park (eds.), Human Interaction with Complex Systems: Conceptual Principles and Design Practice (pp. 291-305). Norwell: Kluwer.

The reality: what we found!





Experiment:

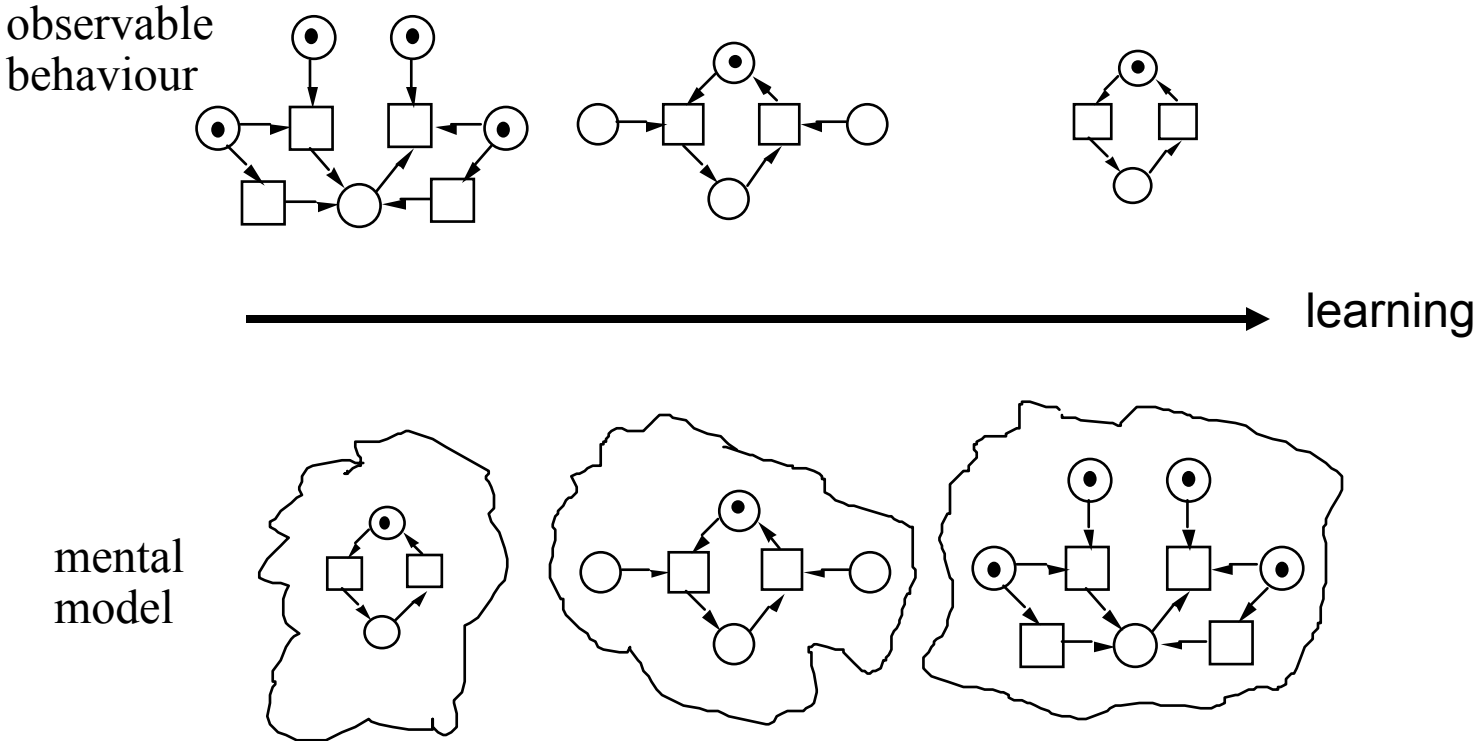
N=6 novices; N=6 experts

4 tasks with a database

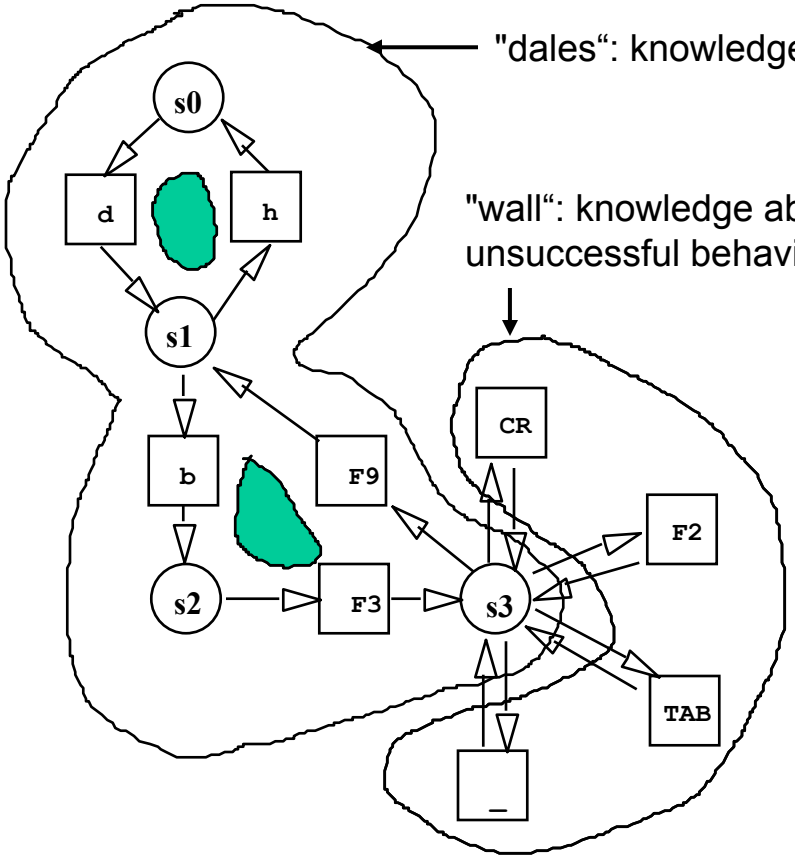
Metric BC=C_{cycle}

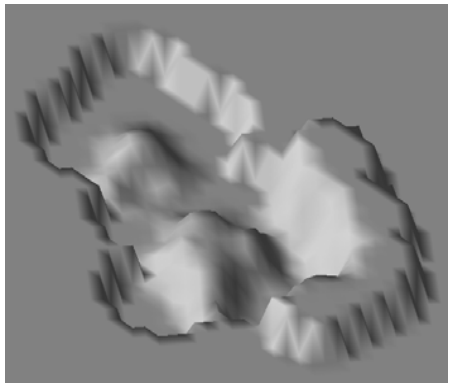
We found a **negative** correlation between
Behavior-Complexity BC and [assumed] Cognitive-Complexity CC

The reality: how to interpret?



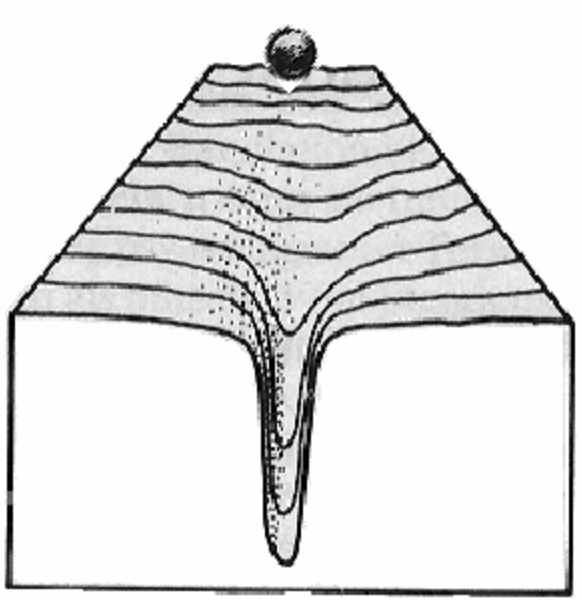
Mental Knowledge Structures: a Metaphor



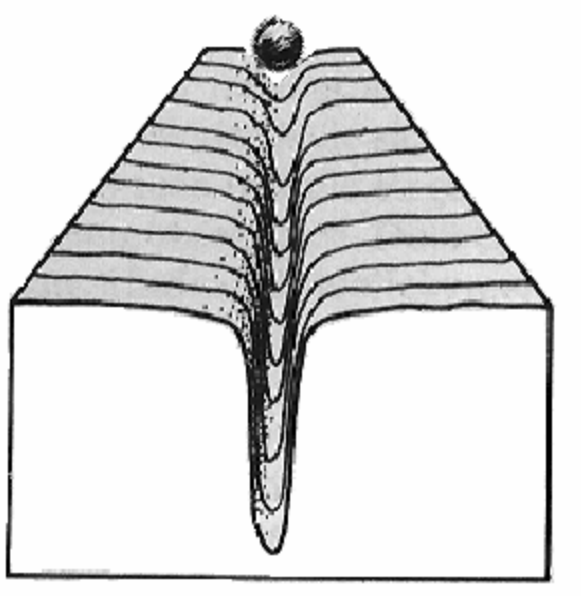


This conclusion would have major impact e.g. on training procedures of operators of complex systems!

Learning: the traditional understanding

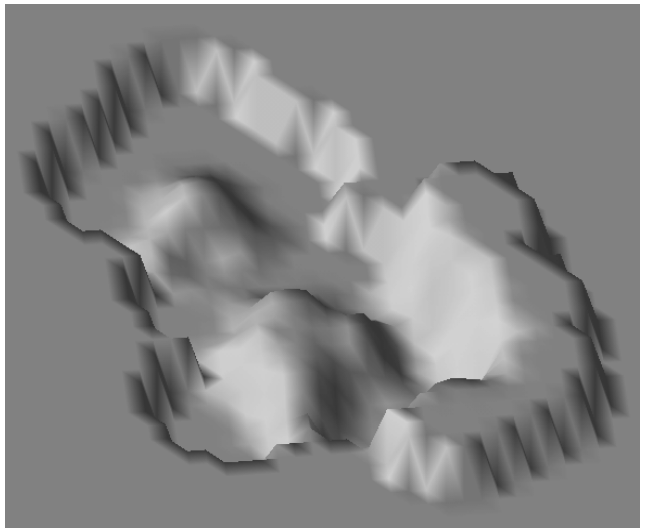


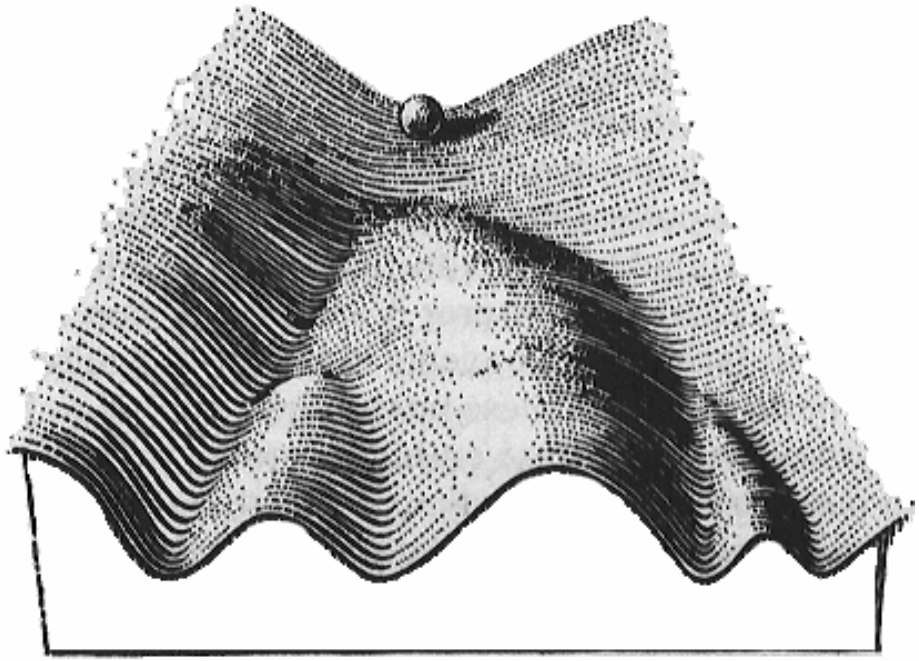
Before learning phase



After learning phase

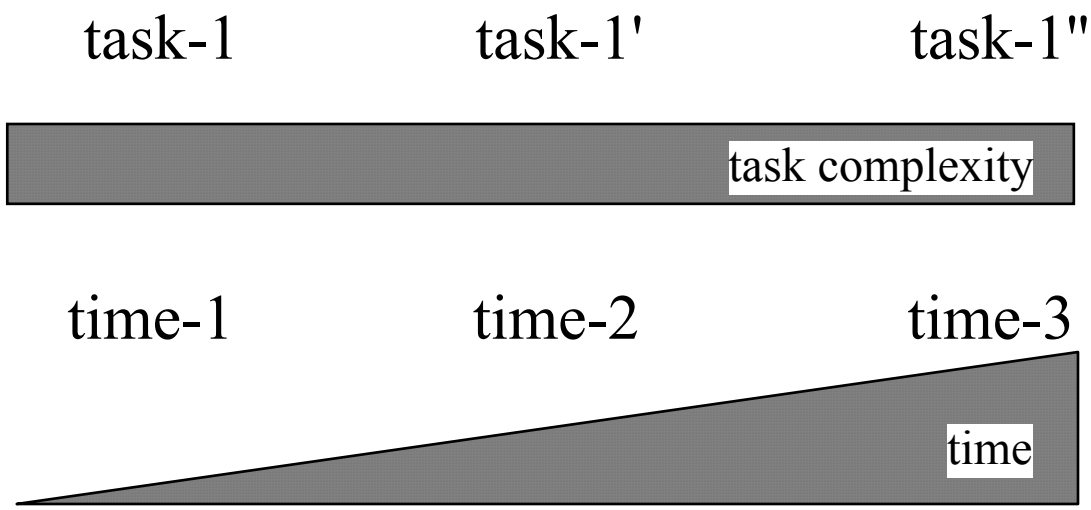
Decision and Action: a new View





Mental decision making for concrete actions is like rolling a ball between hills

Learning and experience

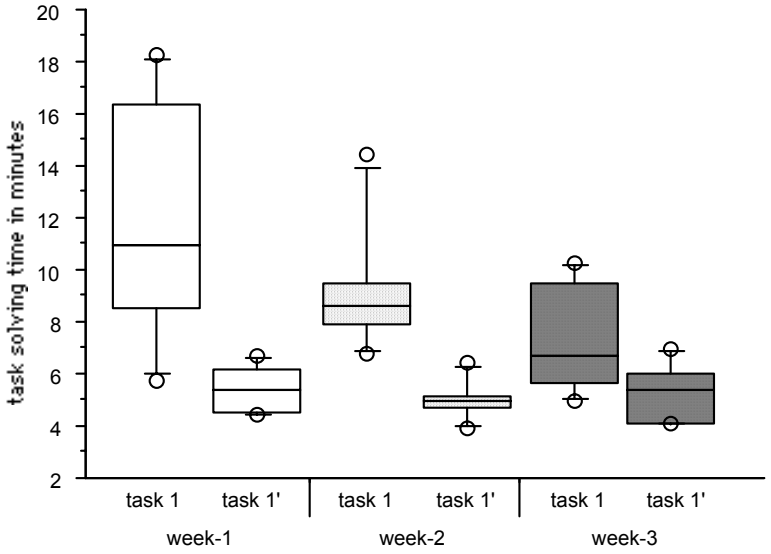


Ref: Rauterberg, M. & Aeppli, R. (1995). Learning in man-machine systems: the measurement of behavioural and cognitive complexity. In: Proceedings of IEEE International Conference on Systems, Man and Cybernetics--SMC'95 (Vol. 5, IEEE Catalog Number 95CH3576-7, pp. 4685-4690). Piscataway: Institute of Electrical and Electronics Engineers.

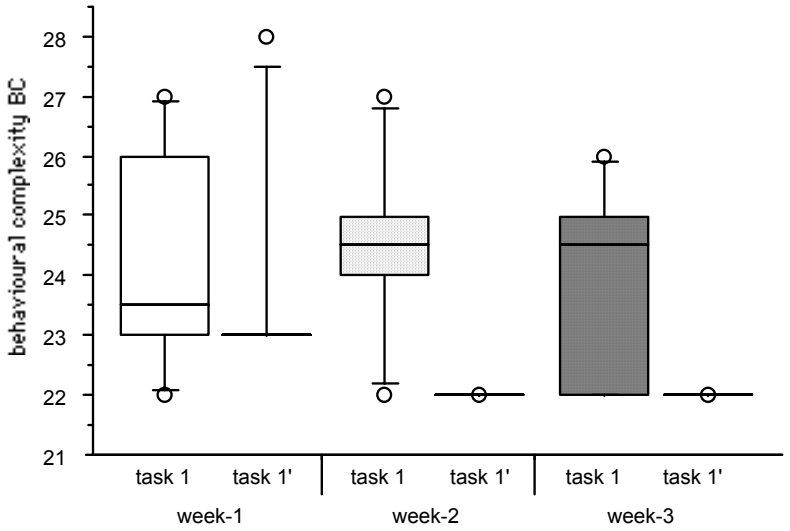
The Learning Experiment

N=6 men (average age of 25 ± 3 years)

Task solving time



Behavioral complexity



Time structure and knowledge structure are different!

Conclusions

- A valid metric for task complexity based on task structure allows an objective comparison
- Automatic analysis for unconstrained task solving behavior allows analysis with applied statistics
- A new analysis and modeling approach leads to new insights…

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Thank you for your attention.