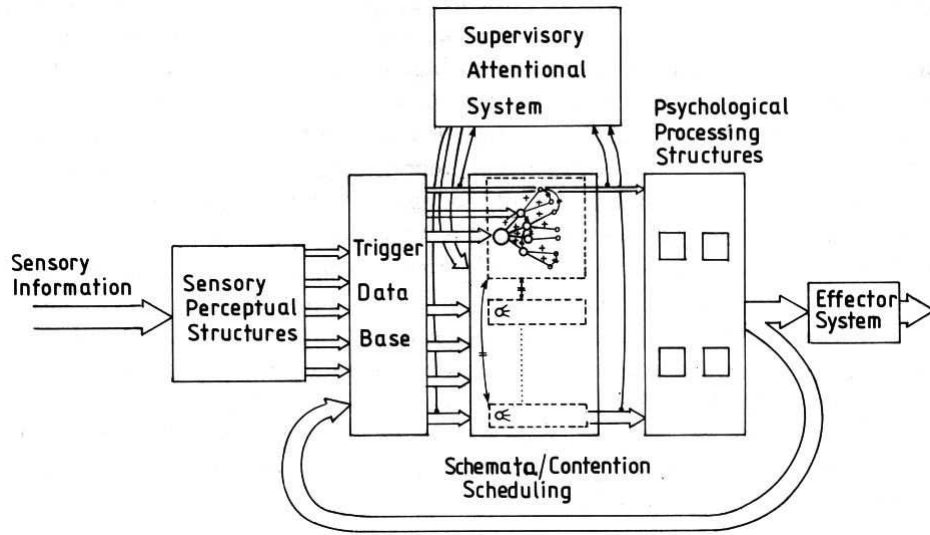


## Norman and Shallice (1986)

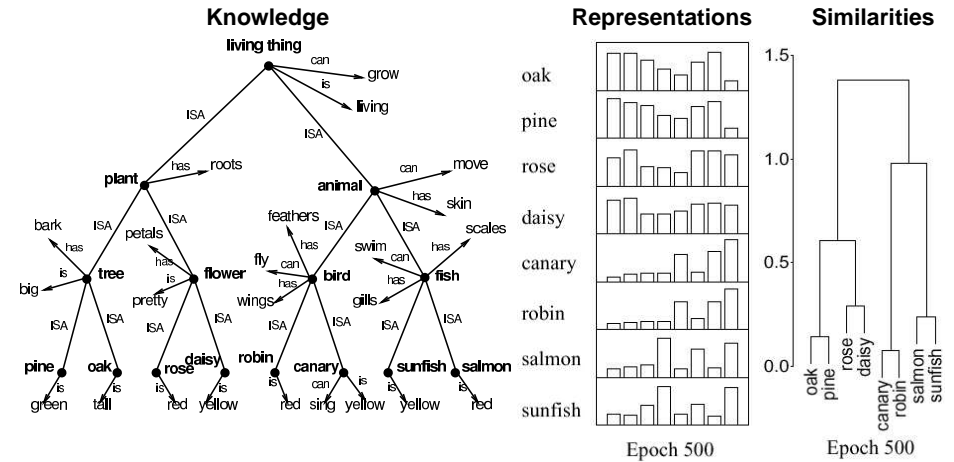


1

## Hierarchical structure in conceptual knowledge

Quillian (1967)  
Collins and Quillian (1969)

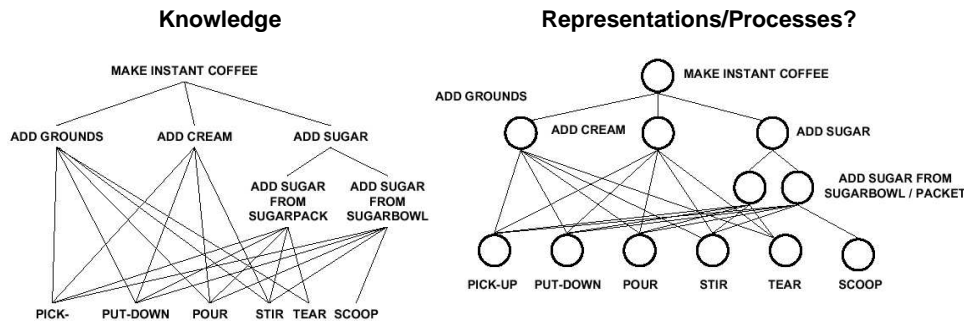
Hinton (1981)  
Rumelhart and Todd (1993)  
McClelland, McNaughton and O'Reilly (1995)  
Rogers and McClelland (in preparation)



3

## Hierarchical structure in routine sequential action

Miller, Gelanter and Pribram (1960), Estes (1972), Rumelhart and Norman (1982)  
Shank and Abelson (1977), MacKay (1985, 1987), Fuster (1989), Grafman (1995)  
Forde and Humphreys (1998), Cooper and Shallice (2000)



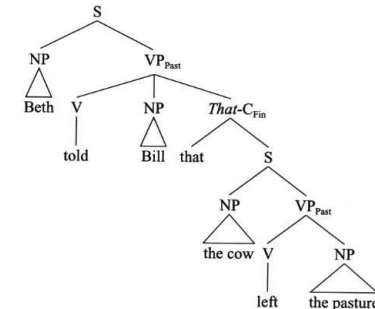
### Problems

- Weak learning theory for when (and how) to elaborate vs. add schemata
- No intrinsic sequencing mechanism

2

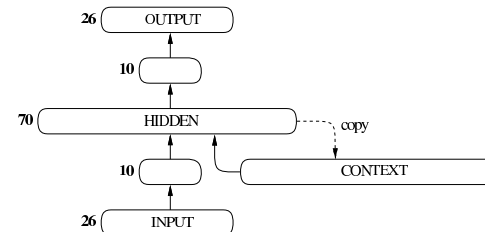
## Hierarchical structure in sentence processing

"Beth told Bill that the cow left the pasture."



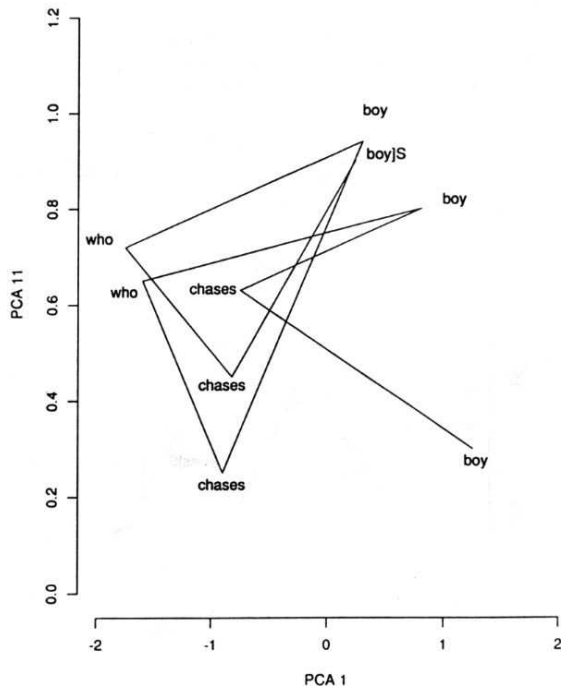
### Elman (1991, 1993)

- Simple recurrent network trained to predict words in pseudo-English sentences



S → NP VI . | NP VT NP .  
 NP → N | N RC  
 RC → who VI | who VT NP | who NP VT  
 N → boy | girl | cat | dog | Mary | John | boys | girls | cats | dogs  
 VI → barks | sings | walks | bites | eats | bark | sing | walk | bite | eat  
 VT → chases | feeds | walks | bites | eats | chase | feed | walk | bite | eat

4



Boy chases boy who chases  
boy who chases boy .

### Principal Components Analysis (PCA) of network's internal representations

- Largest amount of variance (PC-1) reflects **word class** (noun, verb, function word)
- Separate dimension of variation (PC-11) encodes **syntactic role** (agent/patient) for nouns and **level of embedding** for verbs

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## Target phenomena

### Normal performance

- Hierarchically structured
- Actions/subtasks may appear in multiple contexts
- Environmental cues alone sometimes insufficient to guide action selection
- Subtasks may be disjoint or executed in variable order

### Slips of action (Reason, 1990)

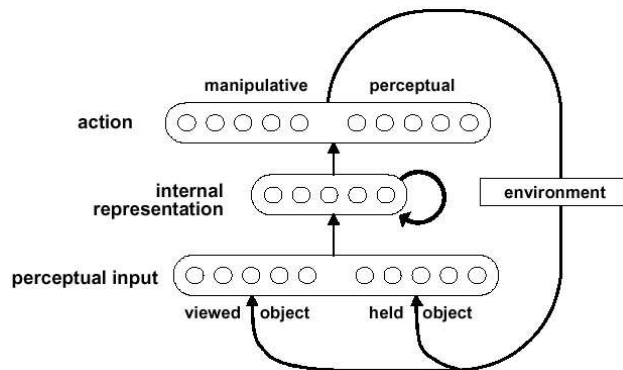
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7

## Distributed connectionist approach to sequential action



- Simple recurrent network that maps perceptual inputs *and* internal representations of task context onto actions
  - Input codes currently viewed object and currently held object
  - Output actions are manipulative (PICK-UP, STIR) or perceptual (LOCATE-CUP)
  - Manipulative actions operate on viewed object ("deictic"; Ballard et al., 1996)
  - External environment updates perceptual input based on action outcome

6

"Neural network models of serial order... [retain] a dynamics dependent on chaining... They also seem to us unlikely to be prone to the kinds of serial order errors discussed below [omissions, transpositions]."

—Houghton and Hartley (1995, *Psyche*, p. 5)

Recurrent networks lack "temporal competence... the intrinsic dynamics that would enable them to progress autonomously through a sequence."

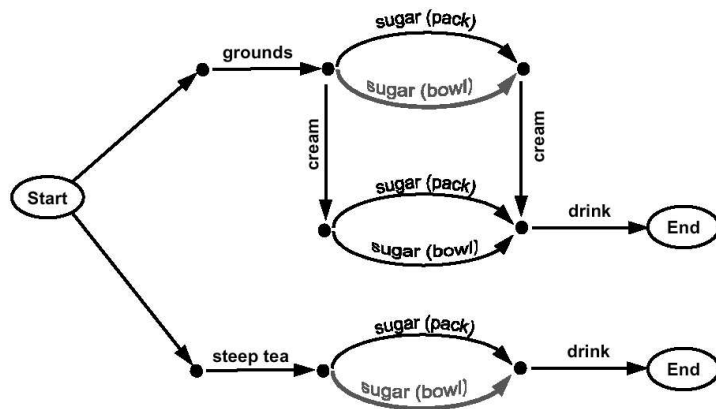
—Brown, Preece and Hulme (2000, *Psych. Review*, p. 133)

"We know of no work in which such networks have been shown to be able to account for errors of the type observed in the action domain (specifically omission and other sequence errors)."

—Cooper and Shallice (2000, *Cog. Neuropsych.*, p. 329)

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## Task structure: Making instant coffee (and tea)



- Hierarchically structured
- Actions/subtasks may appear in multiple contexts
- Environmental cues alone sometimes insufficient to guide action selection
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## Adding coffee grounds: Detail

Step	Fixated object	Held object	Action
1	cup, 1-handle, clear-liquid	nothing	fixate-coffee-pack
2	packet, foil, untornd	nothing	pick-up
3	packet, foil, untornd	packet, foil, untornd	pull-open
4	packet, foil, torn	packet, foil, torn	fixate-cup
5	cup, 1-handle, clear-liquid	packet, foil, torn	pour
6	cup, 1-handle, brown-liquid	packet-foil-torn	fixate-spoon
7	spoon	packet, foil, torn	put-down
8	spoon	nothing	pick-up
9	spoon	spoon	fixate-cup
10	cup, 1-handle, brown-liquid	spoon	stir
			•
			•
			•
			•

11

	Step	Fixated object	Held object	Action
Grounds	1	cup, 1-handle, clear-liquid	nothing	fi xate-coffee-pack
	2	packet, foil, untornd	nothing	pick-up
	3	packet, foil, untornd	packet, foil, untornd	pull-open
	4	packet, foil, torn	packet, foil, torn	fi xate-cup
	5	cup, 1-handle, clear-liquid	packet, foil, torn	pour
	6	cup, 1-handle, brown-liquid	packet-foil-torn	fi xate-spoon
	7	spoon	packet, foil, torn	put-down
	8	spoon	nothing	pick-up
	9	spoon	spoon	fi xate-cup
	10	cup, 1-handle, brown-liquid	spoon	stir
Sugar (bowl)	11	cup, 1-handle, brown-liquid	spoon	fi xate-sugar
	12	cup, 2-handles, lid	spoon	put-down
	13	cup, 2-handles, lid	nothing	pull-off
	14	cup, 2-handles, sugar	lid	fi xate-spoon
	15	spoon	lid	put-down
	16	spoon	nothing	pick-up
	17	spoon	spoon	fi xate-sugarbowl
	18	cup, 2-handles, sugar	spoon	scoop
	19	cup, 2-handles, sugar	spoon-sugar	fi xate-cup
	20	cup, 1-handle, brown-liquid	spoon-sugar	pour
	21	cup, 1-handle, brown-liquid	spoon	stir
Cream	22	cup, 1-handle, brown-liquid	spoon	fi xate-carton
	23	carton, closed	spoon	put-down
	24	carton, closed	nothing	pick-up
	25	carton, closed	carton, closed	peel-open
	26	carton, open	carton, open	fi xate-cup
	27	cup, 1-handle, brown-liquid	carton-open	pour
	28	cup, 1-handle, light-, brown-liquid	carton-open	fi xate-spoon
	29	spoon	carton-open	put-down
	30	spoon	nothing	pick-up
	31	spoon	spoon	fi xate-cup
	32	cup, 1-handle, light-, brown-liquid	spoon	stir
Drink	33	cup, 1-handle, light-, brown-liquid	spoon	put-down
	34	cup, 1-handle, light-, brown-liquid	nothing	pick-up
	35	cup, 1-handle, light-, brown-liquid	cup, 1-handle, light-, brown-liquid	sip
	36	cup, 1-handle, light-, brown-liquid	cup, 1-handle, light-, brown-liquid	sip
	37	cup, 1-handle, empty	cup, 1-handle, empty	say-done

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## Training and testing

### Training

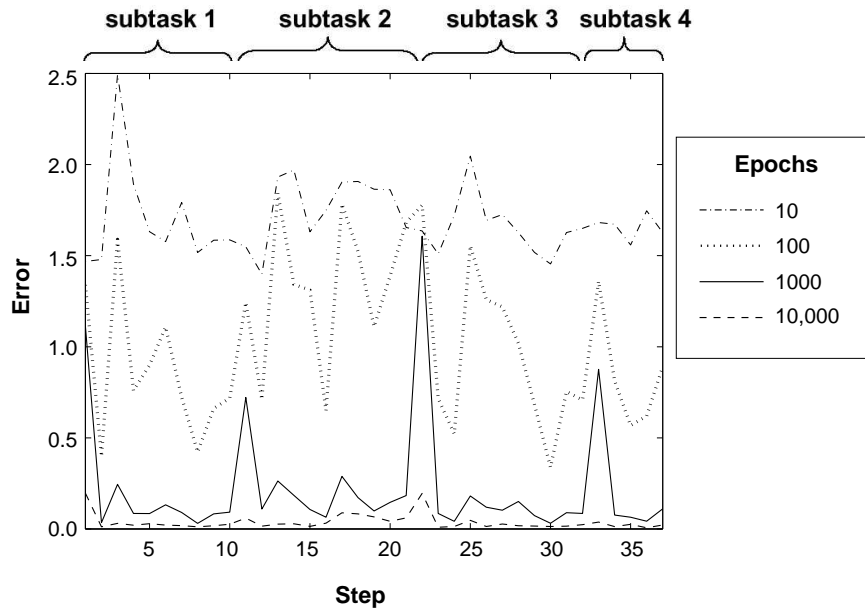
- Initial "context" activations set randomly
- One of two additional perceptual units (INSTRUCT-COFFEE, INSTRUCT-TEA) activated on the *first time-step only*
- Trained to make coffee or tea equally often with paths sampled randomly
  - Correct actions applied to environment (learning: implicit prediction of observed actions)
- Also trained on 267 single-step physically realizable configurations (with distribution of plausible actions as target output)

### Testing

- Most active action unit is selected and applied to environment
- Random initial context (without instruction units) can be used to let network "choose" whether (and how) to make coffee or tea

12

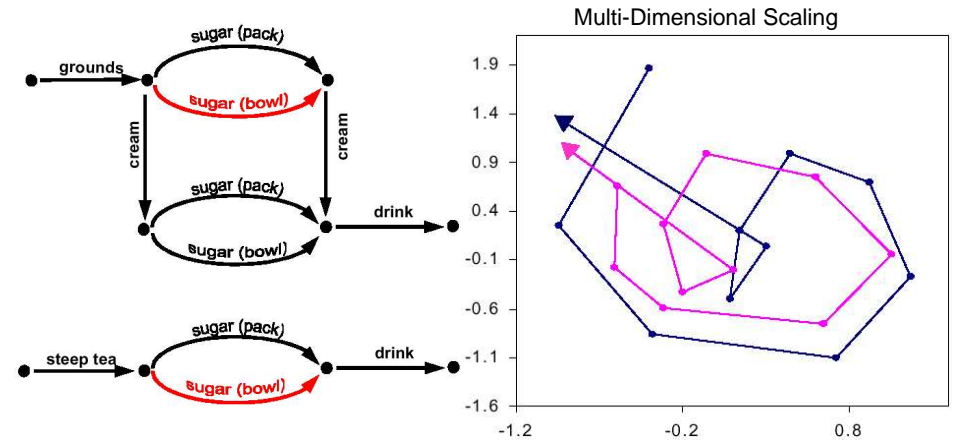
## Acquisition



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## Normal performance: Task context

How are different task contexts maintained across identical subtasks?



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## Normal performance

With coffee instruction

GROUNDS → SUGAR (PACK) → CREAM → DRINK	35
GROUNDS → SUGAR (BOWL) → CREAM → DRINK	37
GROUNDS → CREAM → SUGAR (PACK) → DRINK	14
GROUNDS → CREAM → SUGAR (BOWL) → DRINK	14

With tea instruction

TEABAG → SUGAR (PACK) → DRINK	46
TEABAG → SUGAR (BOWL) → DRINK	54

With no instruction

GROUNDS → SUGAR (PACK) → CREAM → DRINK	15
GROUNDS → SUGAR (BOWL) → CREAM → DRINK	18
GROUNDS → CREAM → SUGAR (PACK) → DRINK	12
GROUNDS → CREAM → SUGAR (BOWL) → DRINK	10
TEABAG → SUGAR (PACK) → DRINK	20
TEABAG → SUGAR (BOWL) → DRINK	25

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## Target phenomena

### Normal performance

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### Slips of action (Reason, 1990)

- Occur at decision points, typically transition points between subtasks
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- Fragmentation of sequential structure: With increasing ADS severity, increase in "independent" actions (actions lying outside a completed subtask)
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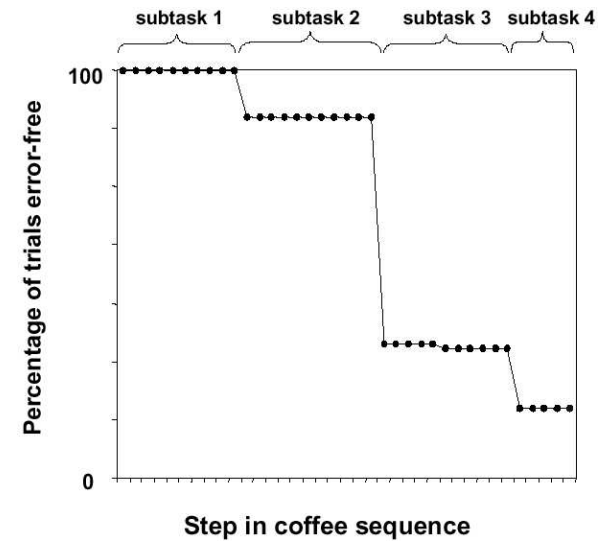
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## Slips of action

Errors occur at **decision points** (boundaries between subtasks)



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## Slips of action

**Distraction:** Distort context activations with **mild-to-moderate noise**

Sample of behavior:

pick-up coffee-pack  
pull-open coffee-pack  
pour coffee-pack into cup  
put-down coffee-pack  
pick-up spoon  
stir cup  
put-down spoon  
pick-up sugar-pack  
tear-open sugar-pack  
pour sugar-pack into cup  
put-down sugar-pack  
pick-up spoon  
stir cup  
put-down spoon  
pick-up cup\*  
sip cup  
sip cup  
say-done

grounds

sugar (pack)

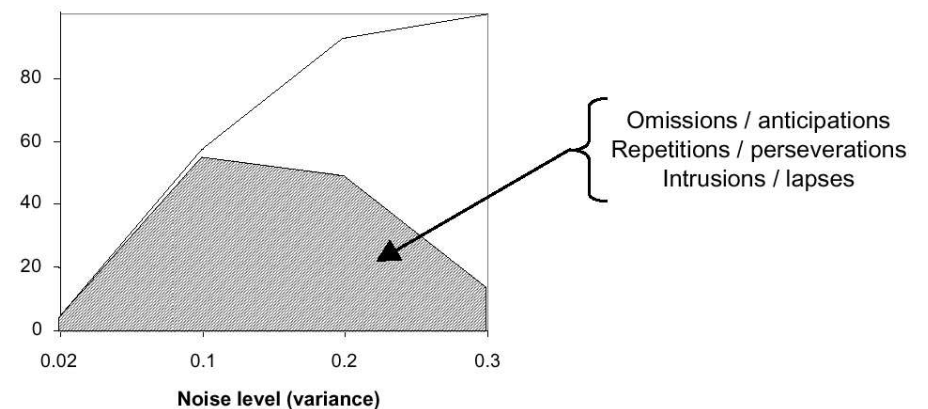
drink

cream omitted →

18

## Slips of action

Errors take the form of **displaced but intact subtask sequences**

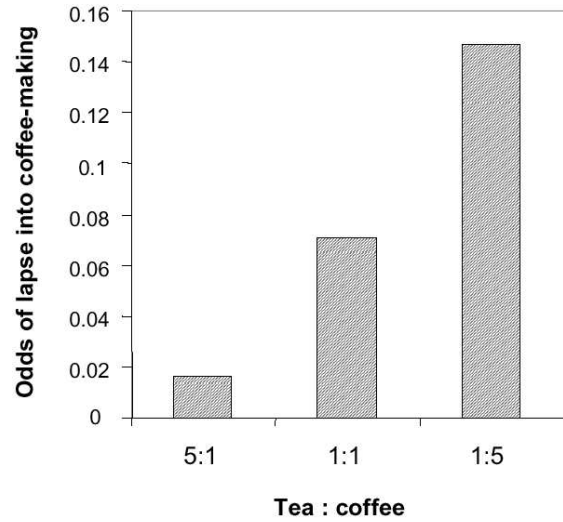


20

## Slips of action

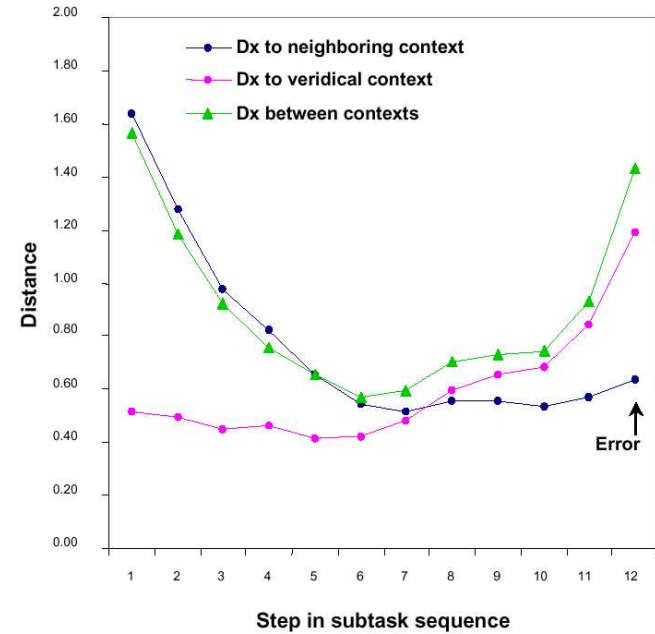
Lapses typically involve shift from less frequent to more frequent task

STEEP-TEA  $\Rightarrow$  ADD-SUGAR  $\Rightarrow$  ADD-CREAM\*



21

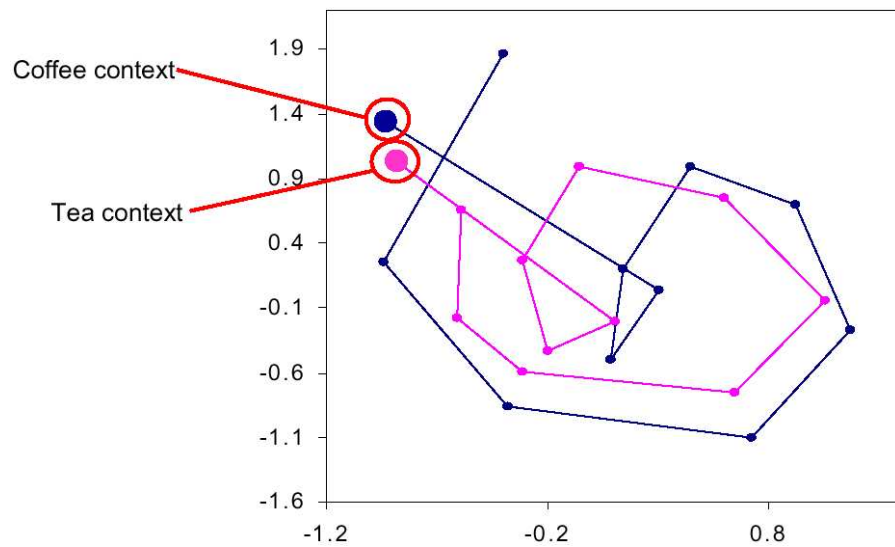
## Slips of action: Analysis



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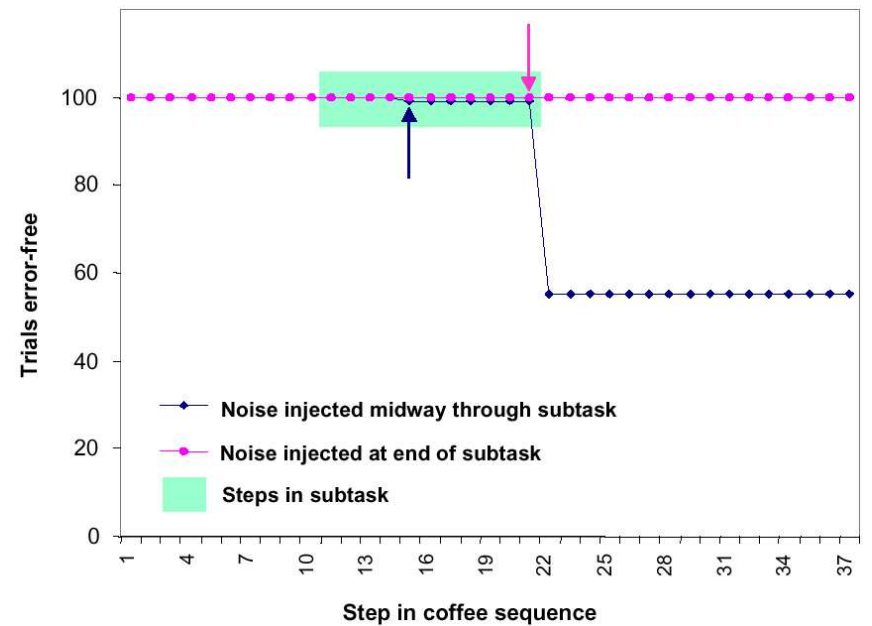
## Slips of action: Analysis

ADD-SUGAR (BOWL) subtask (in coffee vs. tea)



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## Slips of action: Prediction



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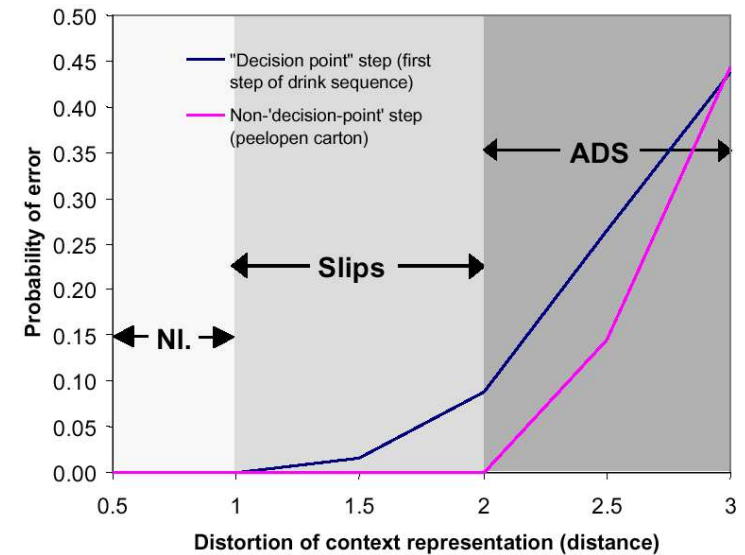
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## Action Disorganization Syndrome

Neural damage: Distort context activations with severe noise



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## Action Disorganization Syndrome

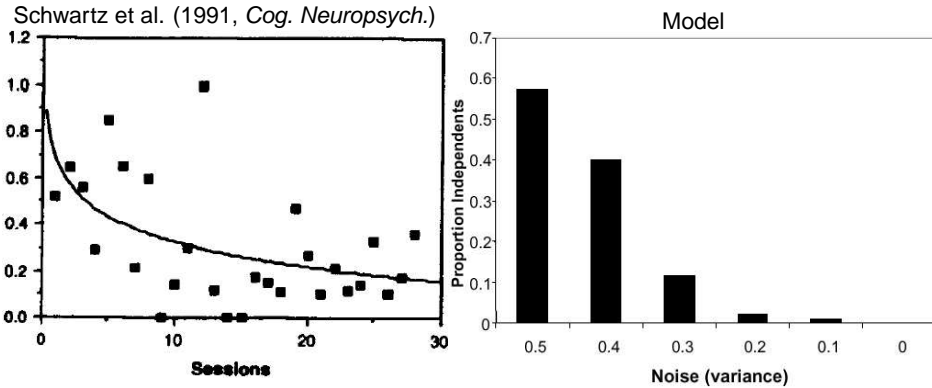
Sample of behavior:

	pick-up coffee-pack	}	<b>disrupted subtask</b>
	pull-open coffee-pack		
	put-down coffee-pack*		
	pick-up coffee-pack		
	pour coffee-pack into cup		
	put-down coffee-pack		
	pick-up spoon	}	<b>subtask fragment</b>
	stir cup		
	put-down spoon		
	pick-up sugar-pack		
	tear-open sugar-pack		
	pour sugar-pack into cup		
	put-down sugar-pack	}	<b>subtask fragment</b>
	pick-up cup*		
	put-down cup		
<b>sugar repeated</b> →	pull-off sugarbowl lid		
	put-down lid		
	pick-up spoon		
	scoop sugarbowl with spoon	}	<b>subtask fragment</b>
	put-down spoon*		
	pick-up cup*		
	sip cup		
	sip cup		
	say-done		

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## Action Disorganization Syndrome

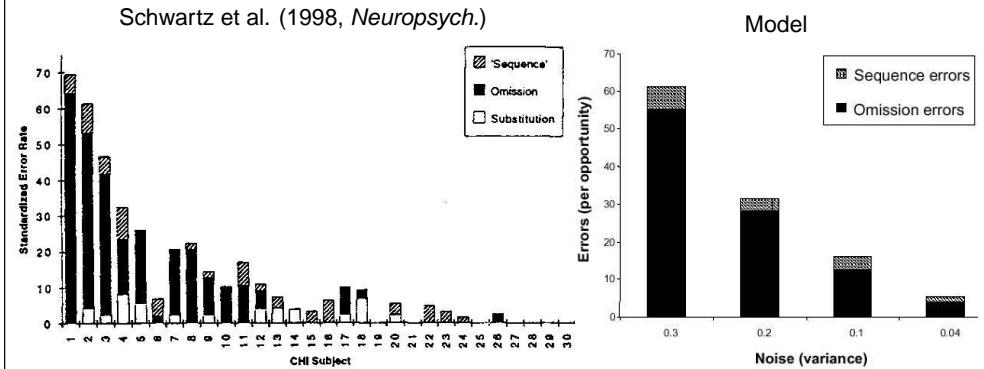
Increase in **independent actions** with increasing ADS severity



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## Action Disorganization Syndrome

Patients who make more errors commit a higher proportion of **omission errors**



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## Action Disorganization Syndrome

Error Type	Example	Percentage	
		Model	Patients
<b>Omission</b>	Sugar not added	<b>77</b>	30–40
<b>Sequence</b>		<b>15</b>	20
Anticipation	Pour cream without opening		
Perseveration	Add cream, add sugar, add cream again		
Reversal	Stir water then add grounds		
<b>Other</b>		<b>8</b>	30
Obj. substitution	Stir with coffee packet		
Gesture substitution	Pour gesture substituted for stir		
Tool omission	Pour sugar bowl into cup		
Action addition	Scoop sugar with bowl lid then put down		
Quality	Pour cream four times in a row		

*Note:* Frequencies are based on a sample of 100 trials under noise with variance 0.2.

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# Summary

## Core assumptions

- Schemas as emergent functional properties of a system mapping from perception to action
- Sequencing mechanism shaped by experience with specific task domains

## Approach

- Recurrent connectionist network
- Deictic specification of object selection
- Learned, distributed representation of task context

## Results

- Applied to normal behavior, slips of action, Action Disorganization Syndrome
- Accounts for data addressed by traditional models
- Improves upon traditional account in several ways
- Gives rise to testable predictions

