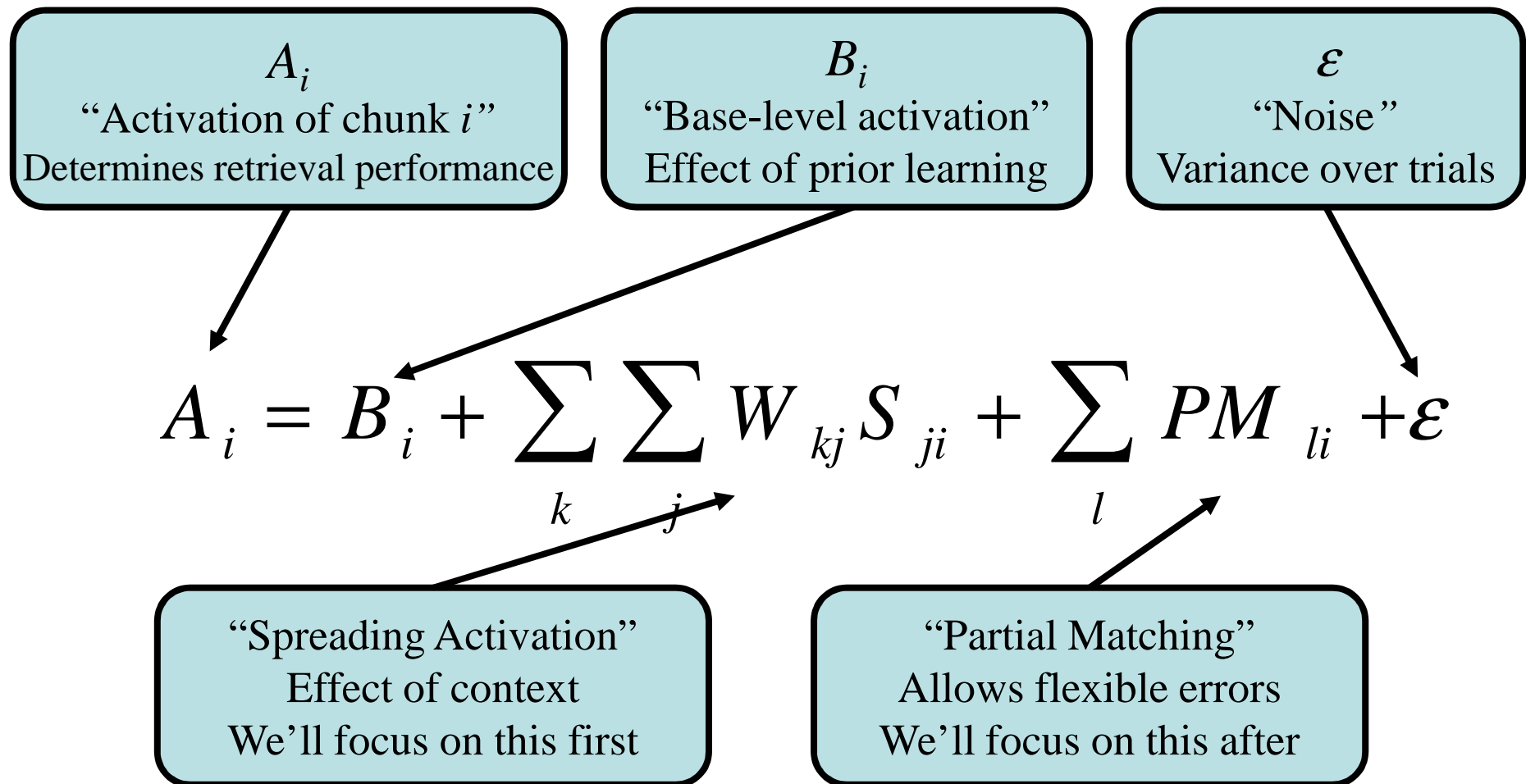


Unit 5:

The Activation Equation



Spreading Activation

$$\sum_k \sum_j W_{kj} S_{ji}$$

- Summed over all elements j in all buffers k (by default just the goal buffer)
- W_{kj} represents the weighting of element j in buffer k
- S_{ji} represents the strength of association between element j and chunk i

$$A_i = B_i + \sum_k \sum_j W_{kj} S_{ji} + \sum_l PM_{li} + \epsilon$$

Attentional Weighting, W_j

$$W_{kj} = \frac{W_k}{n_k}$$

- The more chunk-filled slots n_k in buffer k , the smaller the influence of any particular chunk j
- W_k is the total amount of activation for buffer k and is a settable parameter.
- W_k is defaulted to 1 for the goal buffer (:ga) and 0 for all other buffers (:buffername-activation)
- Like a working memory limitation (see Lovett et al.)

$$A_i = B_i + \sum_k \sum_j W_{kj} S_{ji} + \sum_l PM_{li} + \epsilon$$

Example Retrieval: W_{kj}

```
(p get-help
  =goal>
    ISA      need-help
    class    85-412
==>
  +retrieval>
    ISA      TA
    class    85-412
)
```

```
goal>
  ISA      need-help
  class    85-412
  homework assignment-3

(sgp :ga 1)
```

$$W_{kj} = \frac{W_k}{n_k}$$

What are the sources of activation?

What is W_k ?

What is n_k ?

What is W_{kj} ?

Strength of Association, S_{ji}

- Associative strength from j to chunk i
- $S_{ji} = 0$ if chunk j is not in i , otherwise:
$$S_{ji} = S + \ln(\text{Prob}(i/j))$$
$$= S + \ln(1/\text{fan}_j) = S - \ln(\text{fan}_j)$$
- S is a parameter to be estimated (:mas)
- fan_j - The number of associations of chunk j = the number of chunks in which j appears as a slot + 1

$$A_i = B_i + \sum_k \sum_j W_{kj} S_{ji} + \sum_l PM_{li} + \epsilon$$

Example Retrieval: Fan

```
(p get-help
  =goal>
    ISA      need-help
    class    85-412
==>
  +retrieval>
    ISA      TA
    class    85-412
)
```

What is S ?
What is fan_j for 85-412?

$$S_{ji} = S - \ln(fan_j)$$

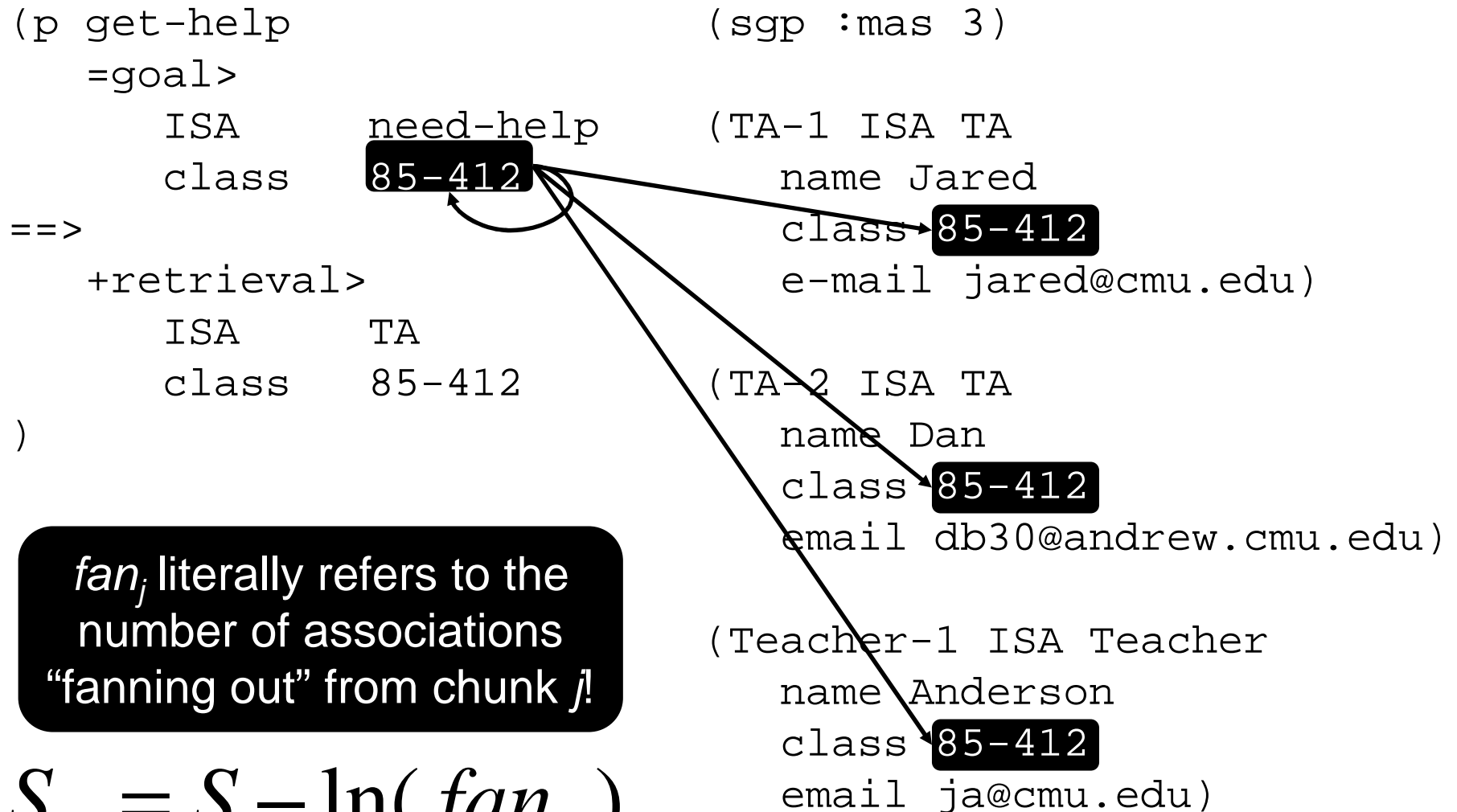
```
(sgp :mas 3)

(TA-1 ISA TA
  name Matt
  class 85-412
  e-mail jared@cmu.edu)

(TA-2 ISA TA
  name Dan
  class 85-412
  email db30@andrew.cmu.edu)

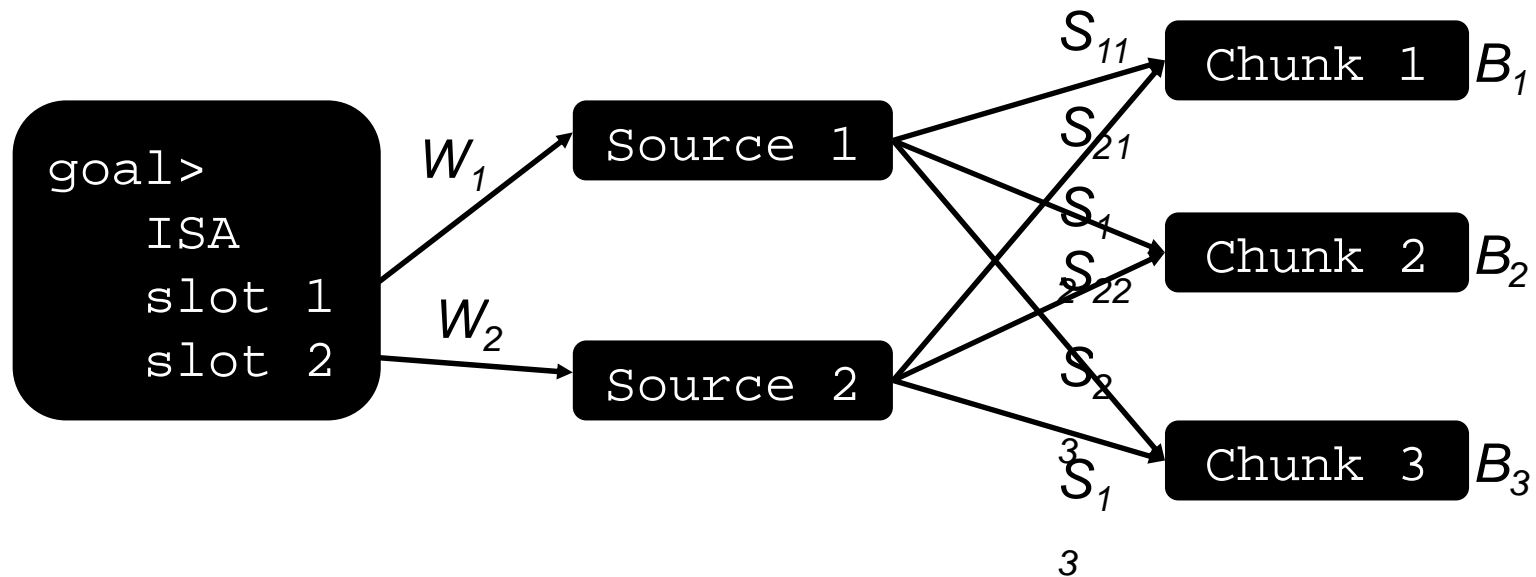
(Teacher-1 ISA Teacher
  name Anderson
  class 85-412
  email ja@cmu.edu)
```

Example Retrieval: Fan



$$S_{ji} = S - \ln(fan_j)$$

Spreading Activation



$$A_1 = B_1 + W_1 S_{11} + W_2 S_{21}$$

$$A_2 = B_2 + W_1 S_{12} + W_2 S_{22}$$

$$A_3 = B_3 + W_1 S_{13} + W_2 S_{23}$$

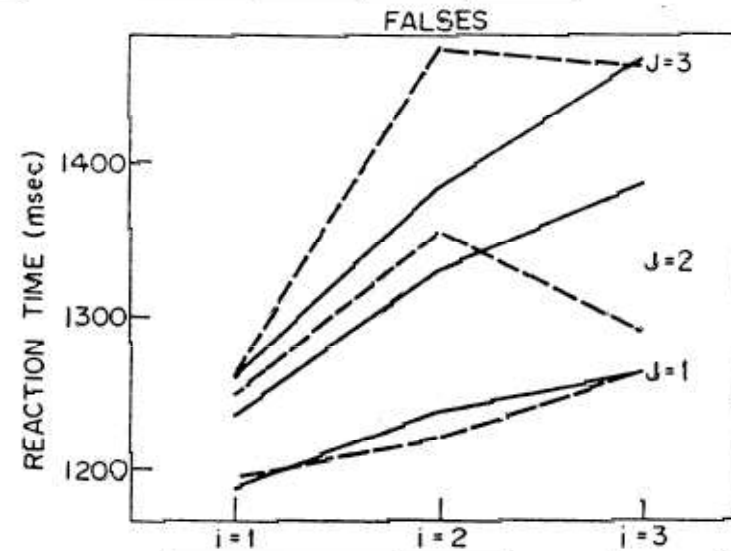
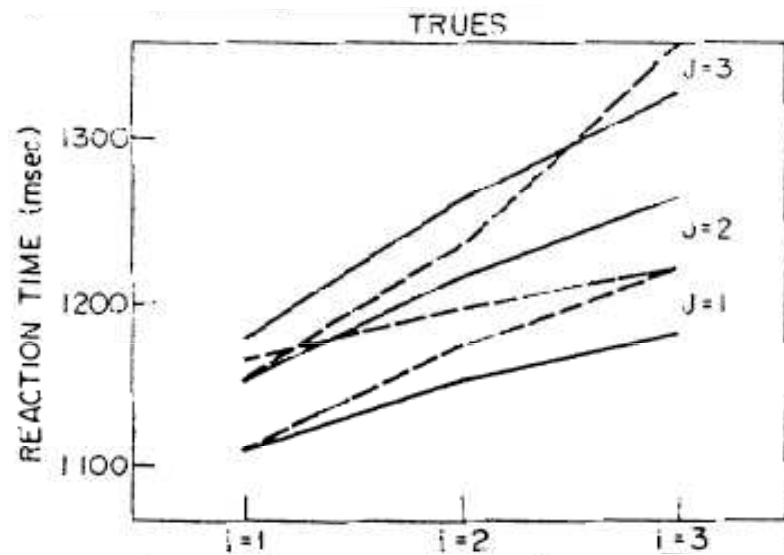
The Fan Experiment

Training: A hippie is in the park
A lawyer is in the cave
A debutante is in the bank
A hippie is in the cave
A lawyer is in the church

- Each *<person>* and each *<location>* occurs 1, 2, or 3 times in the test sentences
- After the learning phase: judge whether a probe was seen (*target*) or not (*foil*)

Test A hippie is in the cave
A lawyer is in the park

The Fan Effect



- RT increases linearly as the fan of person (i) and location (J) increases
- Foils take longer than targets

The Fan Effect Model

- After visually encoding the probe, ends up with a comprehend-sentence chunk like this:

```
=imaginal>  
  ISA comprehend-sentence  
  arg1 =person (e.g., hippie)  
  arg2 =location (e.g., cave)
```

- And requests one of two retrievals

```
+retrieval>  
  ISA comprehend-sentence  
  arg1 =person  
+retrieval>  
  ISA comprehend-sentence  
  arg2 =location
```

- Why not constrain person and location simultaneously?

The Fan Effect Model

- The RT differences are caused solely by differences in retrieval time via spreading activation differences
- The fan effect is caused by smaller S_{ji} s for higher fan stimuli
- **Example target:** The lawyer (fan 1) is in the store (fan 1)

(sgp :imaginal-activation 1 :mas 1.6)

=imaginal>

ISA comprehend-sentence
sentence

arg1 =person

arg2 =location

W_L

W_S

lawyer

store

P13

ISA comprehend-

relation

arg1

arg2

nil

lawyer

store

S_{L-13}

S_{S-13}

$$W_L = W_S = W/n = 1/2$$

$$S_{L-13} = S_{S-13} = S - \ln(\text{fan}) = 1.6 - \ln(2) = 0.906$$

$$A_{13} = B_{13} + W_L S_{L-13} + W_S S_{S-13} = 0 + (0.5 * 0.906) + (0.5 * 0.906) = 0.906$$

The Fan Effect Model

- **Example target:** The hippie (fan 3) is in the bank (fan 2)

- Higher fan leads to lower S_{ji} and higher RT

$$S_{ji} = S - \ln(\text{fan}_j) \qquad \text{Time}_i = Fe^{-A_i}$$

- **Example foil:** The giant (fan 3) is in the bank (fan 2)

- Retrieving a non-match means you only get spreading activation from either the person (giant) or the location (bank), but not both.
 - Lower S_{ji} and higher RT relative to targets

Conclusions:

Spreading Activation

- Any given source of activation decreases its contribution as the number of sources increases (W)
 - Limit on how much can be in the goal and still have successful retrievals
 - Like a working memory capacity
- Spreading activation is smaller if the fan is higher (S_{ji})

$$A_i = B_i + \sum_k \sum_j W_{kj} S_{ji} + \sum_l PM_{li} + \epsilon$$

Partial Matching

- Symbolic systems as too perfect?
- Retrieval requires a perfect match
- Partial matching (:mp) allows for chunks to be retrieved that don't perfectly match the retrieval request
- Takes into consideration the similarity between chunks in the retrieval request and chunks in slots of declarative memories (e.g., you might retrieve “The titan is in the bank” instead of “the giant is in the bank”).
- This allows ACT-R to make confusion errors (bad) and generalize its knowledge (good).

Partial Matching

$$A_i = B_i + \sum_k \sum_j W_{kj} S_{ji} + \sum_l PM_{li} + \epsilon$$

- Summed over all elements l in the retrieval specification
- P is the amount of weighting given to similarity in slot l (:mp, by default 1.0)
- M_{li} is the similarity between the value l in the retrieval specification and the value in the corresponding slot of chunk i . Typically varies between 0 (maximum similarity) and -1 (maximum difference).
- Similarities can be set by the modeler (set-similarities) as can the maximum similarity (:ms) and maximum difference (:md)

Errors in ACT-R

- **Errors of Omission:** Can ACT-R “do nothing?”
 - ACT-R has a tendency to forget weak or decayed chunks. We already covered all the relevant subsymbolic processes for understanding this. B_i decays with time such that unused memories may fall below threshold (τ). This process is stochastic because when noise (ϵ) is present.
- **Errors of Commission:** Can ACT-R do the wrong thing?
 - Partial matching gives ACT-R a mechanism for performing close, plausible errors. Combine the symbolic pattern-matcher with the subsymbolic activation computation by replacing the pass/fail test with activation penalties proportional to the degree of mismatch.

Serial Grouped Recall Model

- Study (123) (456) (789)
- Recall (123) (465) (78)

(setsimilarities

(first second -0.5)

(second third -0.5)

(first third -1))

(add-dm

(list ISA group)

(first isa chunk) (second isa chunk)

(third isa chunk) (fourth isa chunk)

(group1 ISA group parent list position first id group1)

(group2 ISA group parent list position second id group2)

(group3 ISA group parent list position third id group3)

(item1 ISA item name "1" parent group1 position first)

(item2 ISA item name "2" parent group1 position second)

(item3 ISA item name "3" parent group1 position third)

(item4 ISA item name "4" parent group2 position first)

(item5 ISA item name "5" parent group2 position second)

(item6 ISA item name "6" parent group2 position third)

(item7 ISA item name "7" parent group3 position first)

(item8 ISA item name "8" parent group3 position second)

(item9 ISA item name "9" parent group3 position third)

(goal ISA recall-list list list))

Error of Commission

- Retrieve 6 instead of 5
- Activation trace (:act)

```
Computing activation for chunk ITEM5
Total base-level: 0.0
Computing partial matching component
  comparing slot PARENT
  Requested: = GROUP2  Chunk's slot value: GROUP2
  similarity increased by 0.0
  comparing slot POSITION
  Requested: = SECOND  Chunk's slot value: SECOND
  similarity increased by 0.0
Adding transient noise -0.59634924
Chunk ITEM5 has the current best activation -0.59634924

Computing activation for chunk ITEM6
Total base-level: 0.0
Computing partial matching component
  comparing slot PARENT
  Requested: = GROUP2  Chunk's slot value: GROUP2
  similarity increased by 0.0
  comparing slot POSITION
  Requested: = SECOND  Chunk's slot value: THIRD
  similarity increased by -0.5
Total similarity -0.5
Adding transient noise 0.11740411
Chunk ITEM6 is now the current best with activation -0.3825959
```

```
+retrieval>
isa      item
parent   =group
position second
:recently-retrieved nil
```

Error of Omission

- Failure to retrieve 9
- Activation trace (:act)

```
Computing activation for chunk ITEM9
Computing base-level
Starting with blc: 0.0
Total base-level: 0.0
Computing partial matching component
  comparing slot PARENT
    Requested: = GROUP3  Chunk's slot value: GROUP3
    similarity: 0.0
    similarity increased by 0.0
  comparing slot POSITION
    Requested: = THIRD  Chunk's slot value: THIRD
    similarity: 0.0
    similarity increased by 0.0
Total similarity 0.0
Adding transient noise -0.5353896
Adding permanent noise 0.0
Chunk ITEM9 has an activation of: -0.5353896
Chunk ITEM9 has the current best activation -0.5353896
No chunk above the retrieval threshold: -0.5
```

```
+retrieval>
  isa      item
  parent    =group
  position  second
  :recently-retrieved nil
```

Children's Addition (Siegler)

	0	1	2	3	4	5	6	7	8	Other*
1+1	–	.05	.86	–	.02	–	.02	–	–	.06
1+2	–	.04	.07	.75	.04	–	.02	–	–	.09
1+3	–	.02	–	.10	.75	.05	.01	.03	–	.06
2+2	.02	–	.04	.05	.80	.04	–	.05	–	–
2+3	–	–	.07	.09	.25	.45	.08	.01	.01	.06
3+3	.04	–	–	.05	.21	.09	.48	–	.02	.11

*includes no responses

Children's Addition (Siegler)

- **Errors of commission** – PM produces close errors
 - Usually on low side because of extra activation of small facts
- **Errors of omission** - recall failure produces “other” errors
- The parameters determining fit to the data include:
 - **The similarities between numbers** (*set-similarities*) - affect distribution of errors – set to regular size-based distribution
 - **The activation noise** (*:ans*) - increases errors but also robustness to external errors, e.g., mistakes in backup computations
 - **The retrieval threshold** (*:rt*) - increases “other” errors, but also prevents premature convergence and locking-in of errors
 - **Base level activation of chunks** (*set-base-levels*) – set to reflect occurrence in
 - environment

1-Card Blackjack

- Currently set with normal deck and opponent strategy of hitting when below 15.
- Need to learn against other opponents and decks -- (deck of all 7 and opponent who hits when below 14; deck of only 8, 9, & 10).
- With current setting:
 - Worst Strategy 18+%
 - Optimal Strategy 45+%
 - Hitting all the time 30+%
 - Staying all the time 33+%
 - “Safest” Learning Strategy 37+%

First Game

CL-USER 16 > (play-hands 1)

```
0.000 GOAL SET-BUFFER-CHUNK GOAL GAME-STATE0 REQUESTED NIL
0.000 PROCEDURAL CONFLICT-RESOLUTION
0.050 PROCEDURAL PRODUCTION-FIRED START
0.050 PROCEDURAL CLEAR-BUFFER RETRIEVAL
0.050 DECLARATIVE START-RETRIEVAL
0.050 DECLARATIVE RETRIEVAL-FAILURE
0.050 PROCEDURAL CONFLICT-RESOLUTION
0.100 PROCEDURAL PRODUCTION-FIRED CANT-REMEMBER-GAME
0.100 PROCEDURAL CLEAR-BUFFER IMAGINAL
0.100 PROCEDURAL CLEAR-BUFFER MANUAL
0.100 MOTOR PRESS-KEY s
0.100 PROCEDURAL CONFLICT-RESOLUTION
0.250 PROCEDURAL CONFLICT-RESOLUTION
0.300 IMAGINAL SET-BUFFER-CHUNK IMAGINAL LEARNED-INFO0
0.300 PROCEDURAL CONFLICT-RESOLUTION
0.310 MOTOR OUTPUT-KEY #(2 4)
0.310 PROCEDURAL CONFLICT-RESOLUTION
0.400 PROCEDURAL CONFLICT-RESOLUTION
10.000 ----- Stopped because time limit reached
10.000 GOAL GOAL-MODIFICATION
10.000 PROCEDURAL CONFLICT-RESOLUTION
10.050 PROCEDURAL PRODUCTION-FIRED RESULTS-SHOULD-HIT
I LOSE
10.050 PROCEDURAL CLEAR-BUFFER IMAGINAL
10.050 PROCEDURAL CONFLICT-RESOLUTION
20.000 ----- Stopped because time limit reached
(0 1 0 0)
```

GAME-STATE0-0

ISA GAME-STATE

MC1 5

MC2 8

MC3 NIL

MSTART 13

MTOT 13

MRESULT LOSE

OC1 10

OC2 10

OC3 NIL

OSTART 10

OTOT 20

ORESULT WIN

STATE RESULTS

BUST NIL

LEARNED-INFO0-0

ISA LEARNED-INFO

MC1 5

ACTION "h"

Second Game

CL-USER 19 > (play-hands 1)

```
20.000 GOAL          GOAL-MODIFICATION
20.000 PROCEDURAL    CONFLICT-RESOLUTION
20.050 PROCEDURAL    PRODUCTION-FIRED START
20.050 PROCEDURAL    CLEAR-BUFFER RETRIEVAL
20.050 DECLARATIVE   START-RETRIEVAL
20.050 DECLARATIVE   RETRIEVED-CHUNK LEARNED-INFO0-0
20.050 DECLARATIVE   SET-BUFFER-CHUNK RETRIEVAL LEARNED-INFO0-0
20.050 PROCEDURAL    CONFLICT-RESOLUTION
20.100 PROCEDURAL    PRODUCTION-FIRED REMEMBER-GAME
20.100 PROCEDURAL    CLEAR-BUFFER RETRIEVAL
20.100 PROCEDURAL    CLEAR-BUFFER IMAGINAL
20.100 PROCEDURAL    CLEAR-BUFFER MANUAL
20.100 MOTOR         PRESS-KEY h
20.100 PROCEDURAL    CONFLICT-RESOLUTION
20.300 IMAGINAL       SET-BUFFER-CHUNK IMAGINAL LEARNED-INFO1
20.300 PROCEDURAL    CONFLICT-RESOLUTION
20.350 PROCEDURAL    CONFLICT-RESOLUTION
20.400 PROCEDURAL    CONFLICT-RESOLUTION
20.500 MOTOR         OUTPUT-KEY #(6 4)
20.500 PROCEDURAL    CONFLICT-RESOLUTION
20.650 PROCEDURAL    CONFLICT-RESOLUTION
30.000 -----      Stopped because time limit reached
30.000 GOAL          GOAL-MODIFICATION
30.000 PROCEDURAL    CONFLICT-RESOLUTION
30.050 PROCEDURAL    PRODUCTION-FIRED RESULTS-SHOULD-HIT
I BUST
30.050 PROCEDURAL    CLEAR-BUFFER IMAGINAL
30.050 PROCEDURAL    CONFLICT-RESOLUTION
40.000 -----      Stopped because time limit reached
(0 1 0 0)
```

```
GAME-STATE0-0
ISA GAME-STATE
MC1 10
MC2 2
MC3 10
MSTART 12
MTOT 22
MRESULT BUST
OC1 7
OC2 10
OC3 NIL
OSTART 7
OTOT 17
ORESULT WIN
STATE RESULTS
BUST NIL

LEARNED-INFO1-0
ISA LEARNED-INFO
MC1 10
ACTION "h"
```

Recall & ACT

GAME-STATE0-0
ISA GAME-STATE
MC1 10
MC2 2
MC3 NIL
MSTART 12
MTOT NIL
MRESULT NIL
OC1 7
OC2 NIL
OC3 NIL
OSTART 7
OTOT NIL
ORESULT NIL
STATE START
BUST NIL

```
(p start
  =goal>
    isa game-state
    state start
    MC1 =c
==>
  =goal>
    state retrieving
  +retrieval>
    isa learned-info
    MC1 =c
)
```

LEARNED-INFO0-0
ISA LEARNED-INFO
MC1 5
ACTION "h"

```
(p remember-game
  =goal>
    isa game-state
    state retrieving
  =retrieval>
    isa learned-info
    action =act
==>
  =goal>
    state done
  +imaginal>
    isa learned-info
    action =act
  +manual>
    isa press-key
    key =act

  =retrieval>
    MC1 nil
    action nil
  -retrieval>
)
```

Learning a New Chunk

GAME-STATE0-0
ISA GAME-STATE
MC1 10
MC2 2
MC3 10
MSTART 12
MTOT 22
MRESULT BUST
OC1 7
OC2 10
OC3 NIL
OSTART 7
OTOT 17
ORESULT WIN
STATE RESULTS
BUST NIL

(p results-should-hit
=goal>
isa game-state
state results
mresult =outcome
MC1 =c
=imaginal>
isa learned-info
==>
!output! (l =outcome)

=imaginal>
MC1 =c
action "h"
-imaginal>
)

(spp results-should-hit :u 10)

(p results-should-stay
=goal>
isa game-state
state results
mresult =outcome
MC1 =c
=imaginal>
isa learned-info
==>
!output! (l =outcome)

=imaginal>
MC1 =c
action "s"
-imaginal>
)

LEARNED-INFO1-0
ISA LEARNED-INFO
MC1 10
ACTION "h"

Improvement 1: Testing for Hitting

```
GAME-STATE0-0
ISA GAME-STATE
MC1 10
MC2 2
MC3 10
MSTART 12
MTOT 22
MRESULT BUST
OC1 7
OC2 10
OC3 NIL
OSTART 7
OTOT 17
ORESULT WIN
STATE RESULTS
BUST NIL
```

```
(p results-should-hit
=goal>
  isa game-state
  state results
  mresult =outcome
  MC1 =c
  Tests-for-hitting
=imaginal>
  isa learned-info
==>
!output! (l =outcome)

=imaginal>
  MC1 =c
  action "h"
-imaginal>
)
```

(spp results-should-hit :u 10)

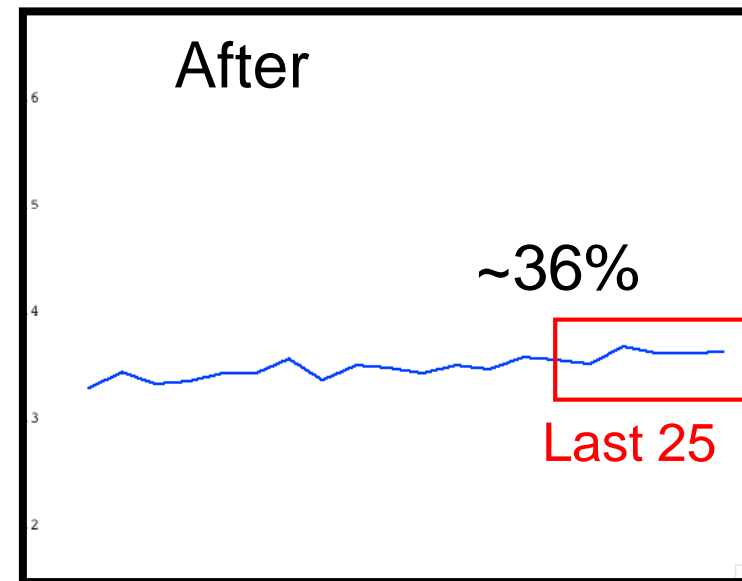
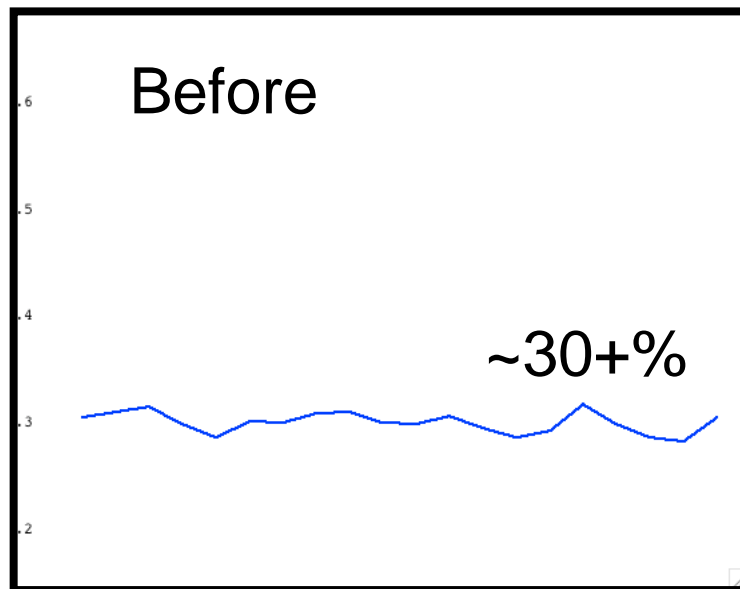
```
(p results-should-stay
=goal>
  isa game-state
  state results
  mresult =outcome
  MC1 =c
  tests-needed-for-staying???
=imaginal>
  isa learned-info
==>
!output! (l =outcome)

=imaginal>
  MC1 =c
  action "s"
-imaginal>
)
```

- Maybe you want to encode multiple productions for hitting
- Maybe you want to encode productions for staying rather than having this the default.

Effect on Performance

(show-learning 500)



Improvement 2: Choosing better features

GAME-STATE0-0
ISA GAME-STATE
MC1 10
MC2 2
MC3 10
MSTART 12
MTOT 22
MRESULT BUST
OC1 7
OC2 10
OC3 NIL
OSTART 7
OTOT 17
ORESULT WIN
STATE RESULTS
BUST NIL

```
(p results-should-hit
=goal>
  isa game-state
  state results
  mresult =outcome
  feature1 =x
  feature2 =y
  Tests-for-hitting
=imaginal>
  isa learned-info
==>
  !output! (l =outcome)

=imaginal>
  feature1 =x
  feature2 =y
  action "h"
-imaginal>
)
```

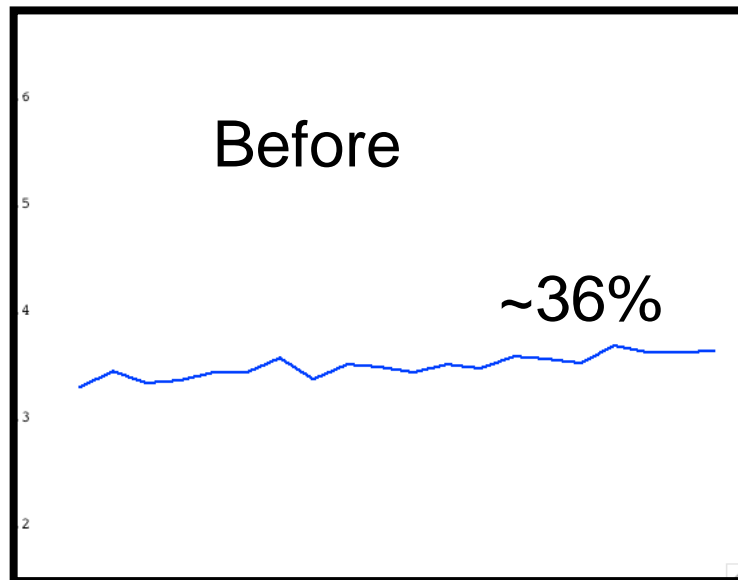
```
(p results-should-stay
=goal>
  isa game-state
  state results
  mresult =outcome
  feature1 =x
  feature2 =y
  tests-needed-for-staying???
=imaginal>
  isa learned-info
==>
  !output! (l =outcome)

=imaginal>
  feature1 =x
  feature2 =y
  action "s"
-imaginal>
)
```

-Slot changes need to be made learned-info chunk-type to have slots which hold the information needed, start production, & remember-game production as well as learning productions such as these.

Effect on Performance

(show-learning 500)



Maximum possible is ~45%

