Usability and Cognitive Models of Program Comprehension

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Goldstone Lab Meeting
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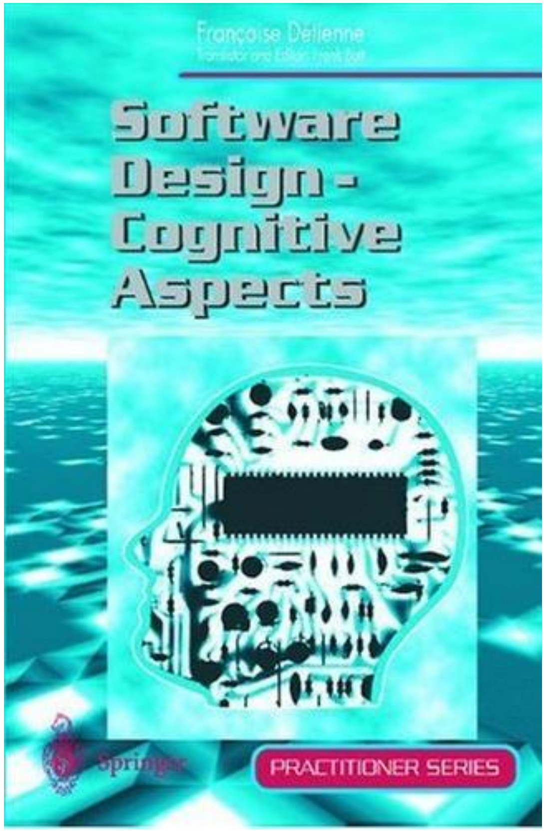

"Many claims are made for the efficacy and utility of new approaches to software engineering – structured methodologies, new programming paradigms, new tools, and so on.

Evidence to support such claims is thin and such evidence, as there is, is largely anecdotal. Of proper scientific evidence there is remarkably little."

- Frank Bott, 2001

Usability Claims

- *"Methods where NbLinesOfCode is higher than 20 are **hard to understand** and maintain. Methods where NbLinesOfCode is higher than 40 are **extremely complex** and should be split in smaller methods (except if they are automatically generated)."*
  - NDepend Code Metrics documentation (2012)

- *"Our experience writing programs in Ur/Web suggests that the feature set we have chosen is **more than sufficient** for our application domain."*
  - Ur/Web meta-programming language overview (2010)

- *"We found that in practice it was **quite difficult** to achieve consistency of usage-site type annotations, so that type errors were not uncommon."*
  - Scala overview (2006)

- *"…it provides a **natural and simple** medium for the expression of a large class of algorithms."*
  - ACM-GAMM report on FORTRAN (1958)

Principles to Follow?

Stepanov, 2007

1. the code should be partitioned into functions;
2. every function should be most 20 lines of code;
3. functions should not depend on the global state but only on the arguments;
4. every function is either general or application specific, where general function is useful to other applications;
5. every function that could be made general – should be made general;
6. the interface to every function should be documented;
7. the global state should be documented by describing both semantics of individual variables and the global invariants.

Veldhuizen, 2007

1. For each component and use case combination, write code that uses the component to implement the use case. If the component cannot be adapted to the use case, then write the simplest possible implementation of the use case without the component.
2. For each component, count the tokens required to:
   - implement the component; and
   - adapt it to each use case.
3. The MDL principle, as adapted for components, suggests that the component minimizing the count of (2) possesses the 'right' level of generality.

Usability Tradeoffs (Blackwell, 2001) – Cog. Dimensions of Notation

- **Abstraction level** – minimum and maximum levels of abstraction exposed by the API
- **Working framework** – size of the conceptual chunk needed to work effectively.
- **Work-step unit** – how much of a programming task can be completed in a single step
- **Progressive evaluation** – what extent partially completed code can be executed
- **Premature commitment** – amount of decisions developers have to make in advance
- **Penetrability** – how the API facilitates exploration and understanding of its components
- **Elaboration** – extent to which the API must be adapted
- **Viscosity** – barriers to change inherent in the API (effort needed to make a change)
- **Consistency** – how much of the rest of an API can be inferred once part of it is learned
- **Role expressiveness** - how apparent relationships are between components & program
- **Domain correspondence** - how clearly API components map to the domain

- Adapted by Clarke, 2004

Which Syntax is Better (Round 1)?

```
var names = select p.Name
            from p in people
```

```
var names = from p in people
            select p.Name
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```
var names = from p in people
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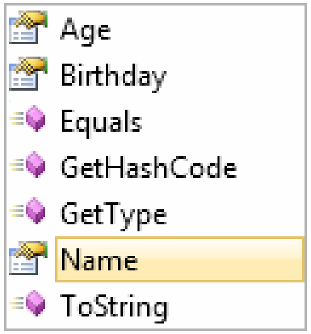
```



Which Syntax is Better (Round 2)?

```
for x in [10, 20, 30]:
    print x
```

```
10
20
30
```

```
for x in [10, 20, 30]:
    for y in [1, 2, 3]:
        print x+y
```

```
11
12
13
21
22
23
31
32
33
```

Which Syntax is Better (Round 2)?

```
for x in [10, 20, 30]; y in [1, 2]:
    print x+y
```

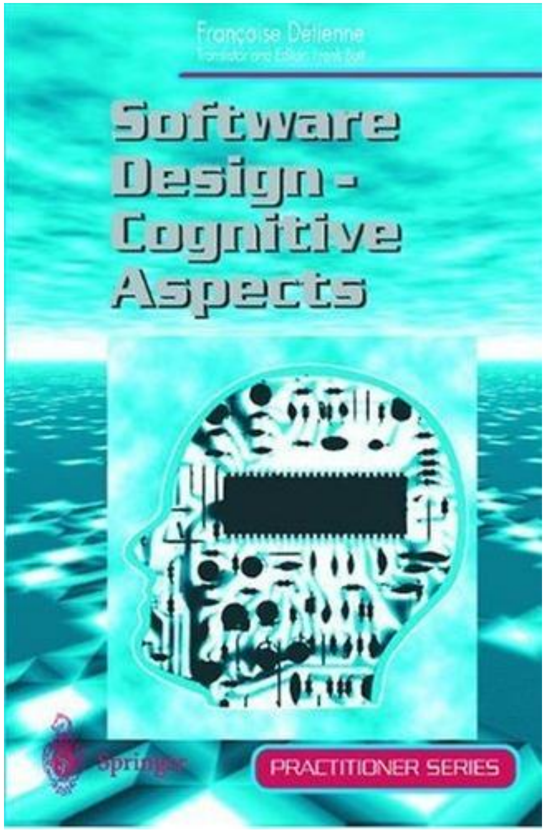
?

Which Syntax is Better (Round 2)?

```
for x in [10, 20, 30]; y in [1, 2]:
    print x+y
```

1st	2nd	3rd
11	11	error!
12	22	
21		
22		
31		
32		

Why?



"Furthermore, such [scientific evidence] as there is can be described as 'black box', that is, demonstrates a correlation between the use of a certain technique and an improvement in some aspect of the development.

It does not demonstrate ***how*** *the technique achieves the observed effect."*

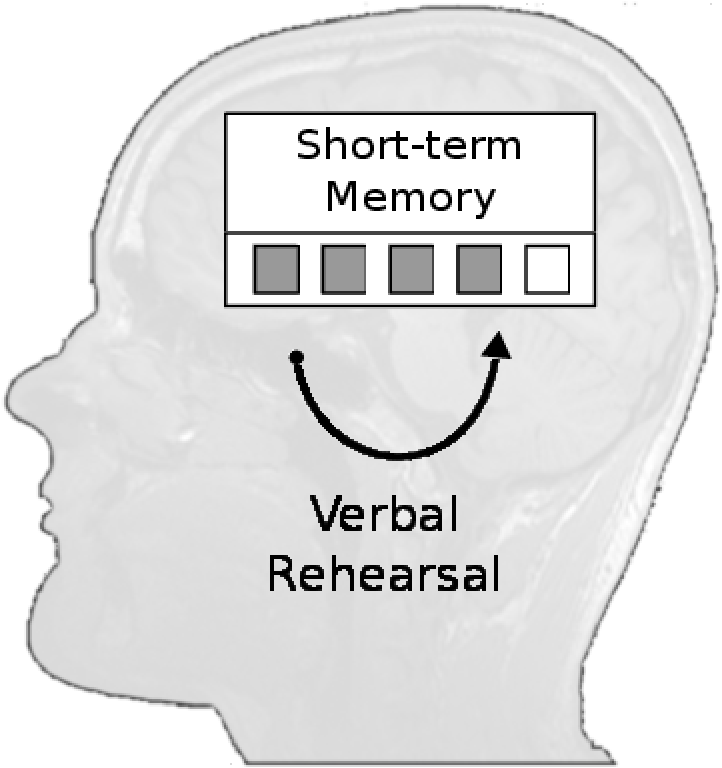
- Frank Bott, 2001

History of the Psychology of Programming

- **First Period** (1960-1979)
  - Imported theories and methods from Psychology
    - Short-term memory, statistics
  - Correlations between task and language/human factors
    - Comments, defects detected
- **Second Period** (1980-present)
  - Cognitive models
    - Knowledge, strategies, task, environment/tools
  - Response times, eye movements, intermediary code
  - Experts and students

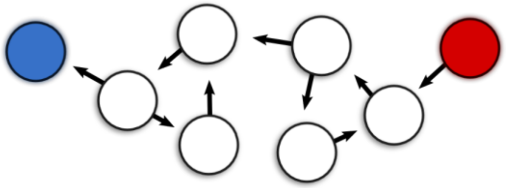
Memory Model of the First Period (1960's – 1970's)

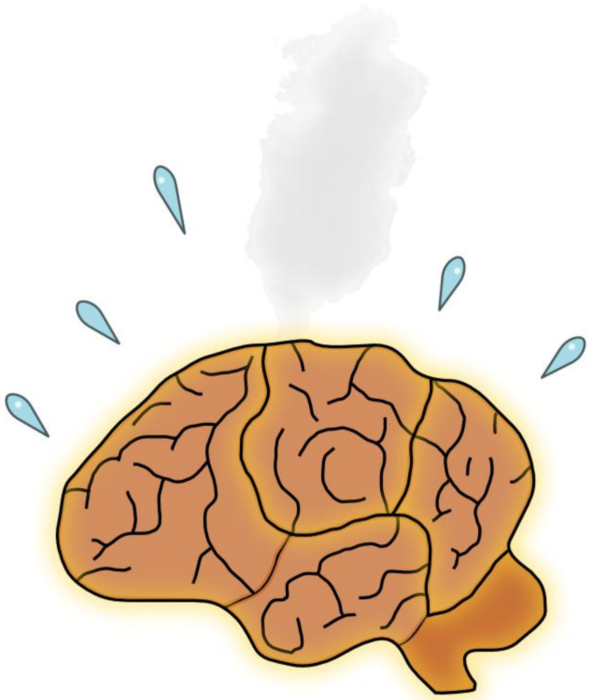
```cpp
#include <iostream>
using namespace std;
int main(int argc, char **argv) {
  cout << "Hello World" << endl;
}
```



Complexity Metrics & Miller's Magic Number

- **Lines of code**
  - Coupled with everything!
- **Cyclomatic Complexity**
  - # of branches
- **Halstead Effort**
  - Operators, operands
- **Object-Oriented metrics**
  - Coupling, cohesion, inheritance





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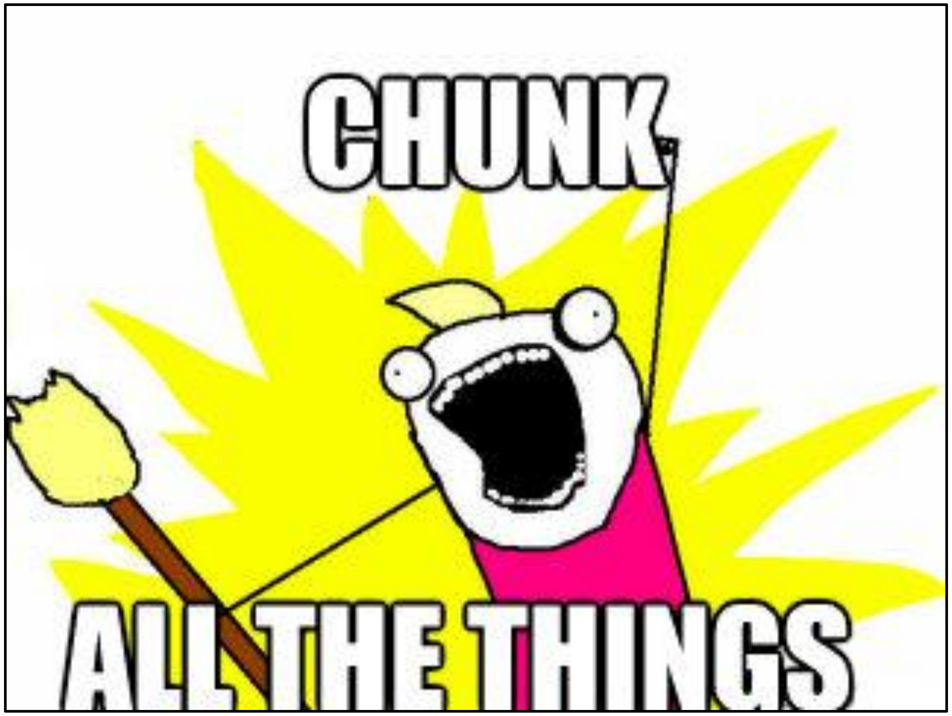
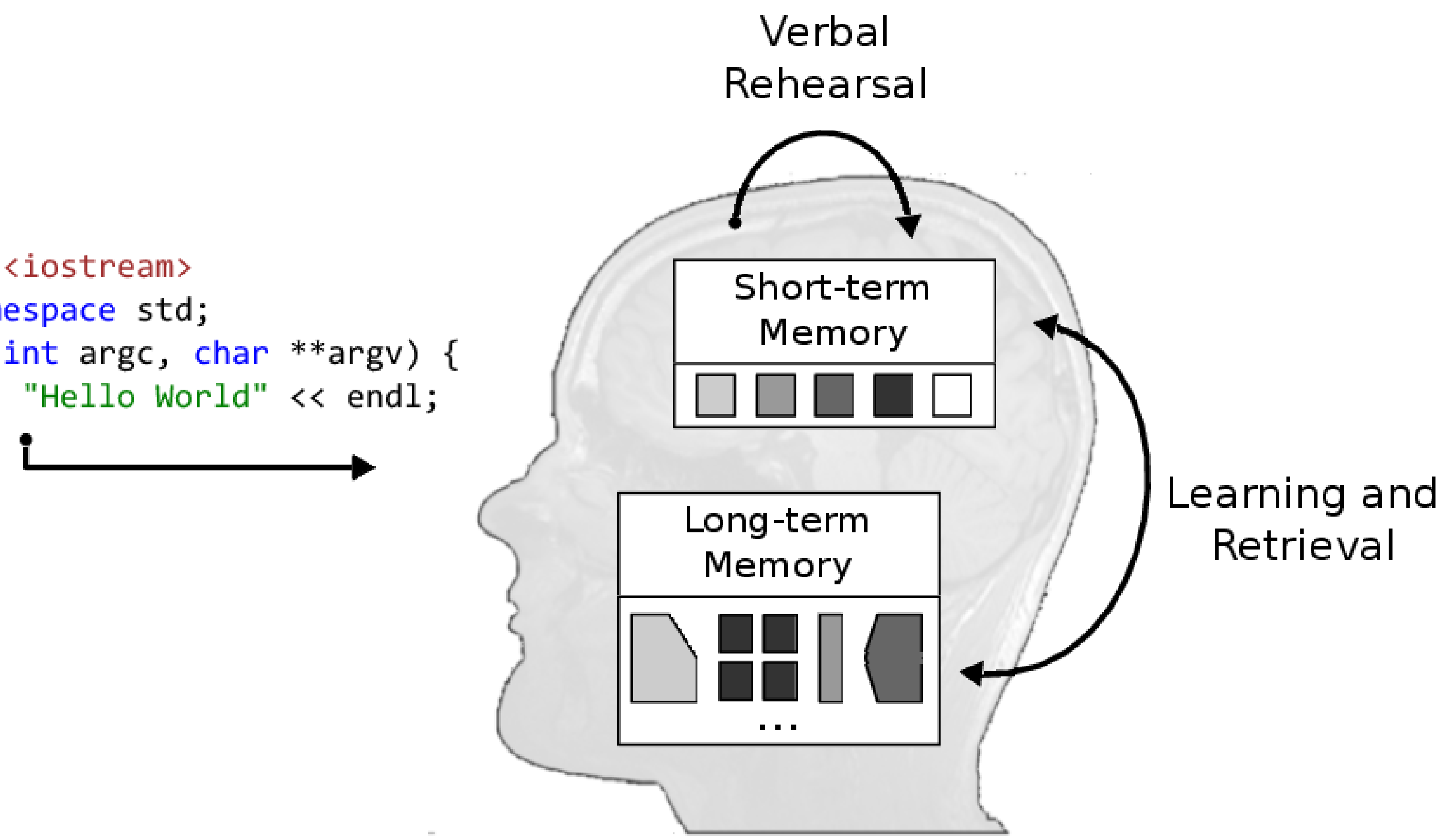
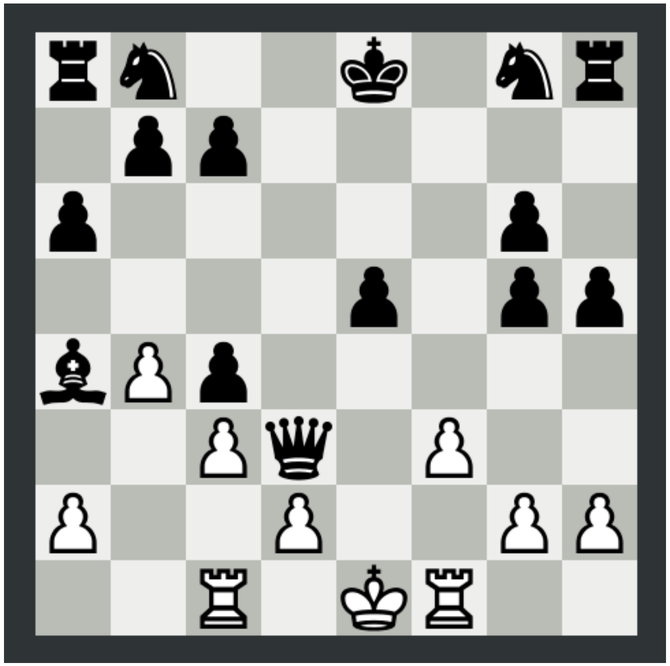

CHUNK
ALL THE THINGS

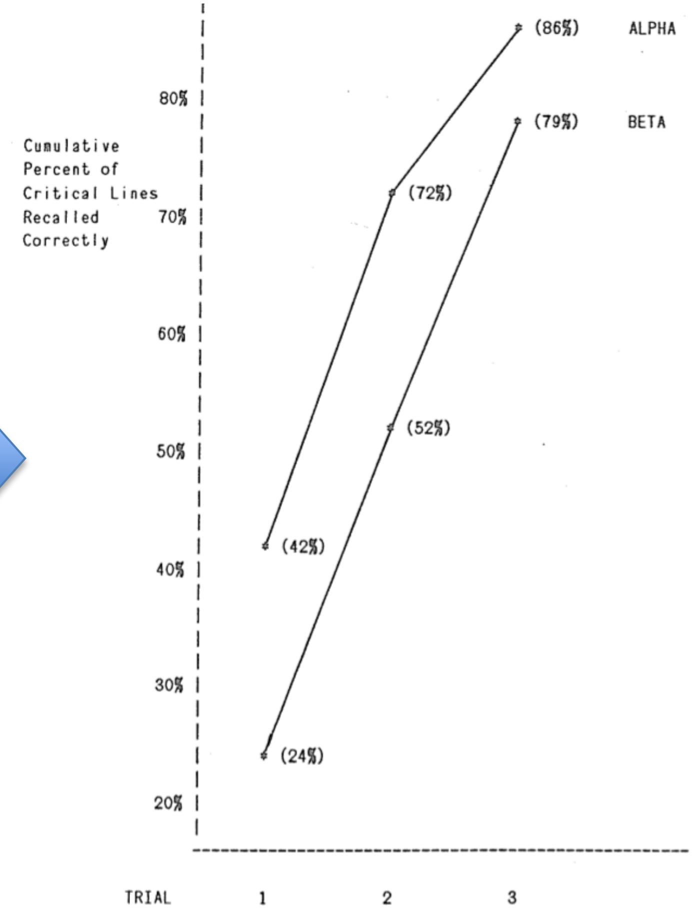
Memory Model of the Second Period (1980's – present)

```
#include <iostream>
using namespace std;
int main(int argc, char **argv) {
  cout << "Hello World" << endl;
}
```



From Chase & Simon (1973) to Soloway & Ehrlich (1984)





What Goes Here (Part 1) ? (Soloway & Erlich, 1984)

```
PROGRAM Green(input, output).
VAR I   INTEGER.
    Letter, LeastLetter   Char.
BEGIN
    LeastLetter  = 'z'.
    FOR I  = 1 TO 10 DO
        BEGIN
          READLN(Letter).
                     -------
          If Letter |       | LeastLetter
                     |       |
                     -------
             THEN LeastLetter  = Letter.
        END.
    Writeln(LeastLetter).
END
```

What Goes Here (Part 1) ? (Soloway & Erlich, 1984)

```
PROGRAM Green(input, output),
VAR I   INTEGER,
    Letter, LeastLetter   Char,
BEGIN
    LeastLetter  = 'z',
    FOR I  = 1 TO 10 DO
        BEGIN
          READLN(Letter),
          If Letter < LeastLetter
             THEN LeastLetter  = Letter,
        END,
    Writeln(LeastLetter),
END
```

```
PROGRAM Green(input, output),
VAR I   INTEGER,
    Letter, LeastLetter   Char,
BEGIN
    LeastLetter  = 'z',
    FOR I  = 1 TO 10 DO
        BEGIN
          READLN(Letter),
                      -------
          If Letter  |       | LeastLetter
                     |       |
                      -------
             THEN LeastLetter  = Letter,
        END,
    Writeln(LeastLetter),
END
```

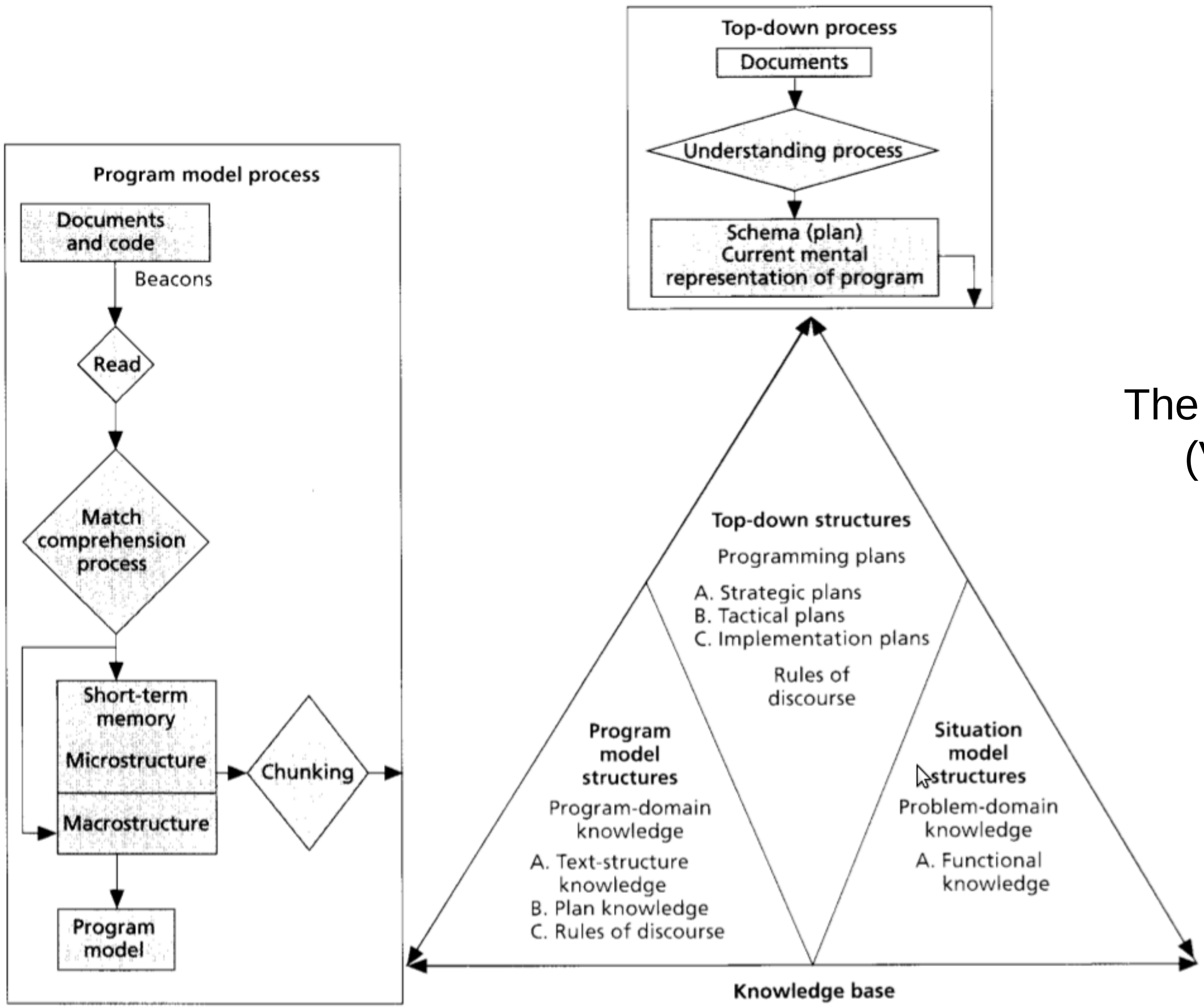
What Goes Here (Part 2) ? (Soloway & Erlich, 1984)

```
PROGRAM Orange(input, output).
VAR Sum, Count, Num   INTEGER,
    Average   REAL,
BEGIN
    Sum  = -99999,
    -------------------------------
    |                             |
    |                             |
    -------------------------------
    REPEAT
        READLN(Num),
        Sum  = Sum + Num,
        Count  = Count + 1,
      UNTIL Num = 99999,
    Average  = Sum/Count,
    WRITELN(Average),
END
```

What Goes Here (Part 2) ? (Soloway & Erlich, 1984)

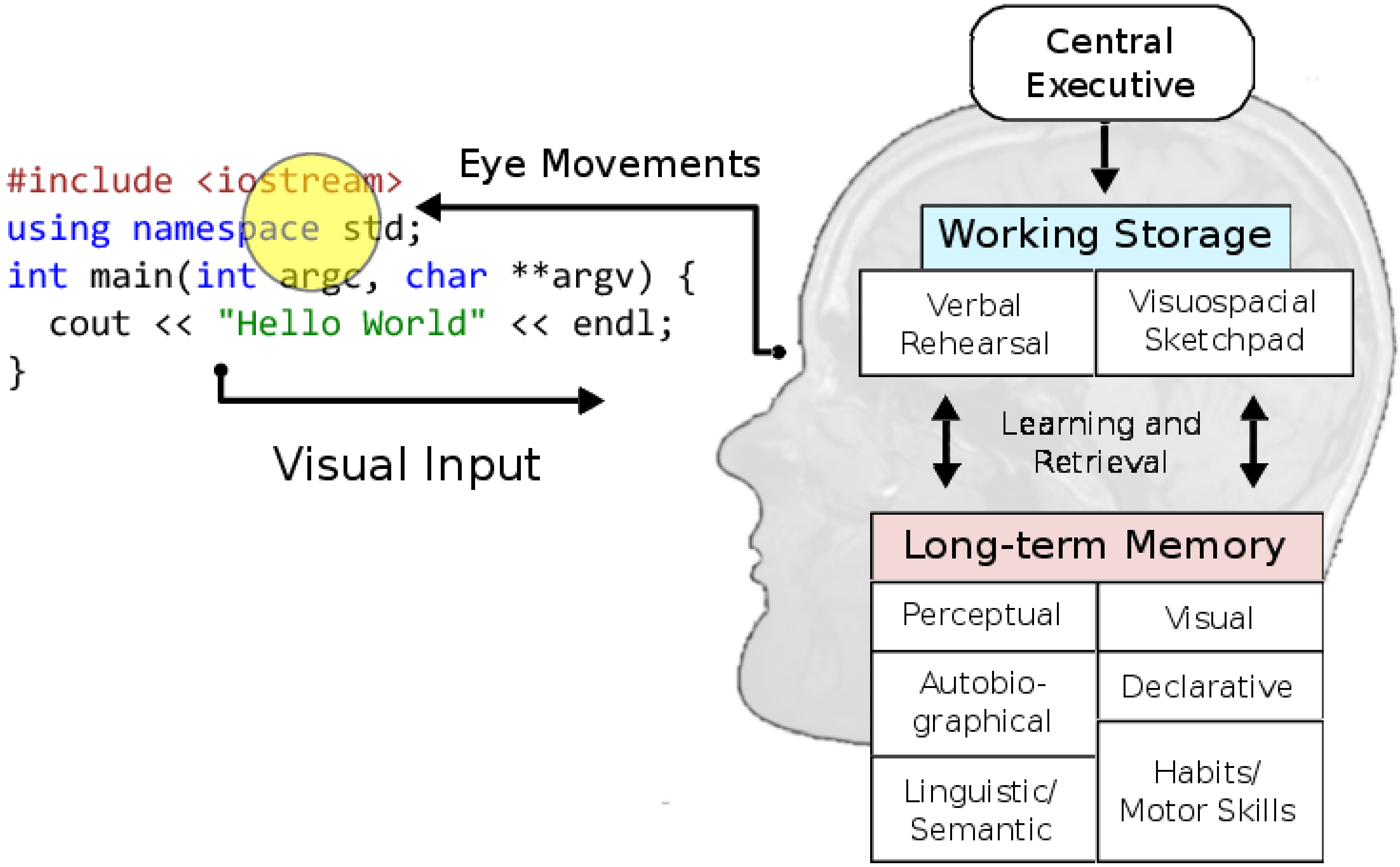
```
PROGRAM Orange(input, output),
VAR Sum, Count, Num   INTEGER,
    Average   REAL,
BEGIN
    Sum  = -99999,
    Count  = -1,
    REPEAT
        READLN(Num),
        Sum  = Sum + Num,
        Count  = Count + 1,
      UNTIL Num = 99999,
    Average  = Sum/Count,
    WRITELN(Average),
END
```

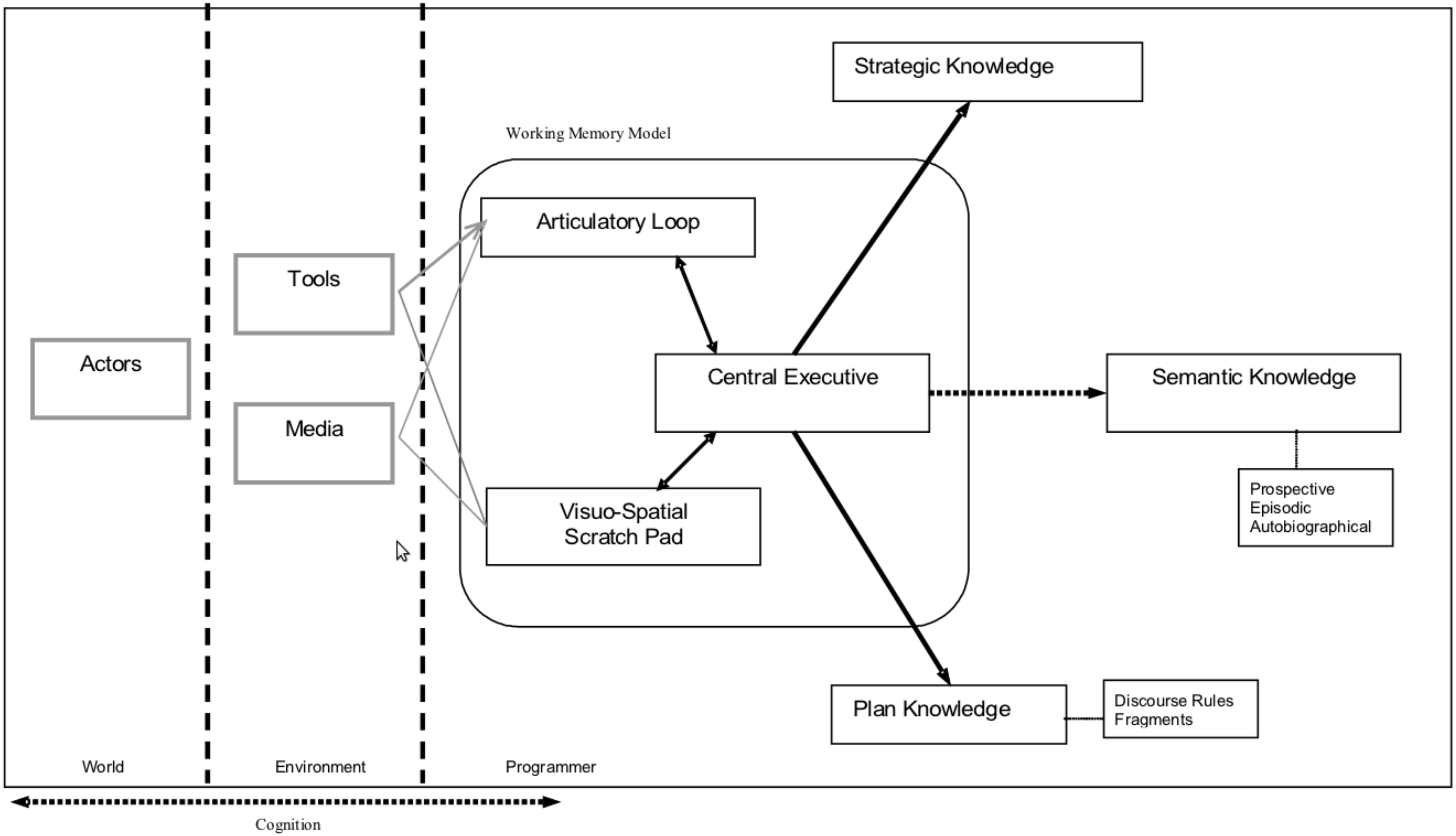
```
PROGRAM Orange(input, output),
VAR Sum, Count, Num   INTEGER,
    Average   REAL,
BEGIN
    Sum  = -99999,
    -------------------------------
    |                             |
    |                             |
    -------------------------------
    REPEAT
        READLN(Num),
        Sum  = Sum + Num,
        Count  = Count + 1,
      UNTIL Num = 99999,
    Average  = Sum/Count,
    WRITELN(Average),
END
```



The Integrated Meta-Model
(Von Mayrhauser, 1995)

More Modern Working Memory Model





The Stores Model of Code Cognition (Douce, 2008)

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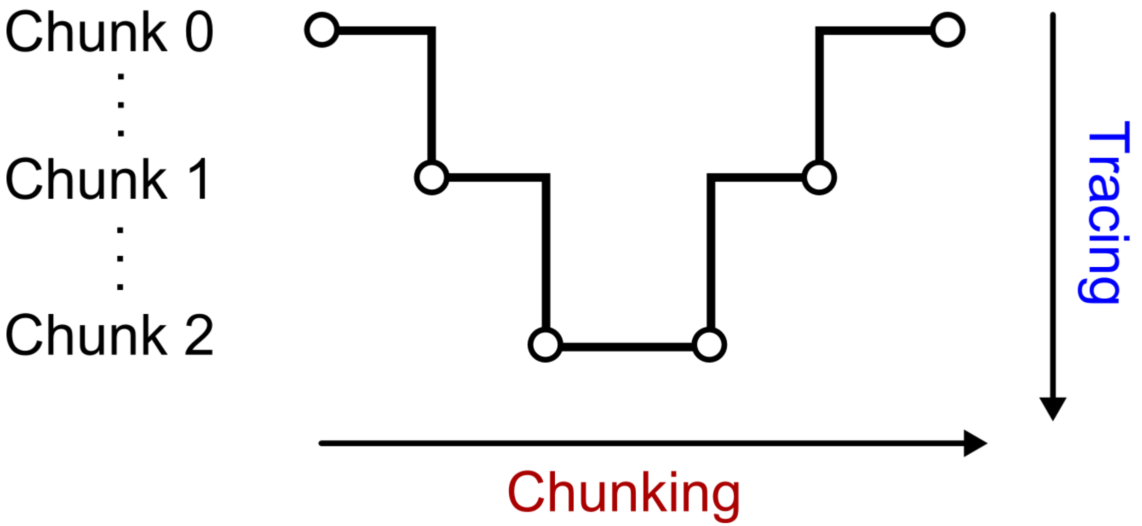
Quantifying Usability Tradeoffs

- **Problems**
  - Models are getting more complex
  - Verbal-conceptual theories
- **Precise Predictions**
  - Can eliminate bad designs with user studies, but…
  - Want to predict trade-offs in advance
  - Choose between “good” designs
- **TODOs**
  - Quantify cognitive model(s)
  - Simulate model(s) with different designs
  - Interpret simulation output as trade-offs

The Cognitive Complexity Metric (Cant, 1995)

$$C_i = \boxed{R_i} + \sum_{j \in N} C_j + \sum_{j \in N} \boxed{T_j}$$



The Cognitive Complexity Metric (Cant, 1995)

$$C_i = R_i + \sum_{j \in N} C_j + \sum_{j \in N} T_j$$

$$R_F(R_S + R_C + R_E + R_R + R_V + R_D)$$

Famil. (Size + Ctrl Struct. + Bool Expr. + Recog. + Visual Struct. + Disrupt.)

Chunk Complexity (R) – 1/3

- R_S = size of chunk
  - $R_S = \begin{cases} aS_i & \text{if } S_i \leq L \\ aS_i + b\left(\frac{S_i - L}{L}\right) & \text{else} \end{cases}$
  - S_i = size measure, L = programmer's limit
- R_C = difficulty in comprehending control structure
  - $R_C = \sum_j C_i(j)p(j)$
  - $C_i(j)$ = complexity of chunk i after j^{th} iteration
  - $p(j)$ is the probability of termination
- R_E = difficulty in comprehending boolean expressions
  - $R_E = b_1 \sum_j B_j$
  - B_j = num. of predicates in j^{th} boolean expression

Chunk Complexity (R) – 2/3

- R_R = recognizability of chunk
  - $R_R = r_R + r_C$
  - $r_R = -\log(\prod_j p(t_j))$, r_C = cohesion measure
  - $p(t_j)$ = prob. of the j^{th} token being drawn from rules of discourse
- R_V = visual structure, layout of the code
  - $R_V = a_1 V$ where $V = \{1, 2, 3\}$
  - 1 = method (easiest), 2 = control structure (harder), 3 = neither (hardest)

Chunk Complexity (R) – 3/3

- R_D = disruptions caused by dependencies
  - $R_D = d\sum_j C_j + e\sum_j T_j$
  - C_j = complexity of sub-chunk j
  - T_j = difficulty in tracing sub-chunk j
- R_F = familiarity of the chunk
  - $R_F = \sum_j f^j$ where f is a review constant ($\approx \frac{2}{3}$)

The Cognitive Complexity Metric (Cant, 1995)

$$C_i = R_i + \sum_{j \in N} C_j + \sum_{j \in N} T_j$$

$$T_F(T_L + T_A + T_S + T_C)$$

Famil. (Localization + Ambiguity + Spacial Dist. + Cueing)

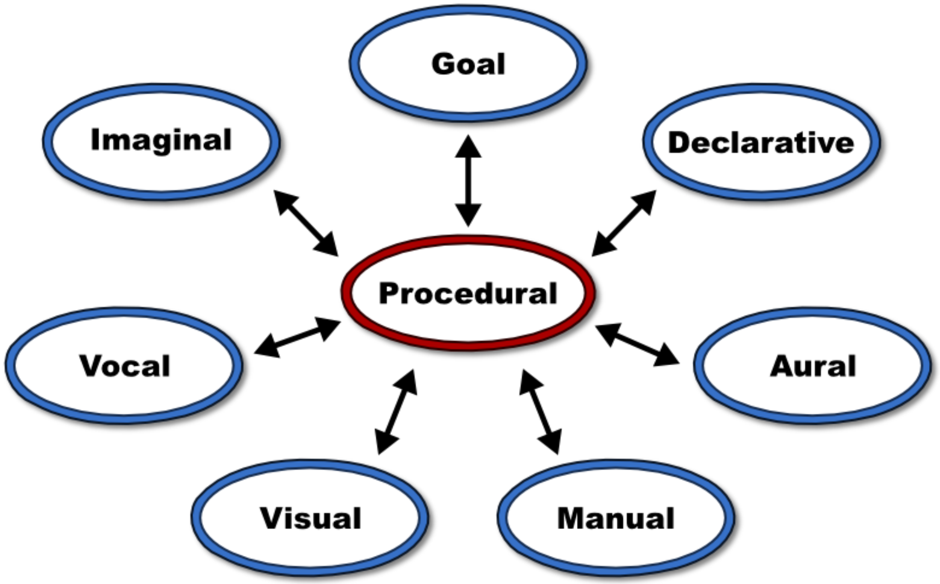
Tracing Difficulty (T) – 1/2

- T_L = localization of dependencies
  - $T_L = a_2 L$ where $L = \{1, 2, 3\}$
  - 1 = embedded (easiest), 2 = local (harder) 3 = remote (hardest)
- T_A = ambiguity
  - $T_A = a_3 A$ where $A = \{0, 1\}$ (1 = is ambiguous)
- T_S = spacial distance
  - $T_S = b_2 \Delta S$ where S = lines of code

Tracing Difficulty (T) – 2/2

- T_C = cueing
  - $T_C = a_4 B$ where $B = \{0, 1\}$ (1 = is obscure)
  - Some chunks are easier to find when not embedded in a larger block of text
- T_F = familiarity
  - $T_F = \sum_j f^j$ where $f \approx \frac{2}{3}$

The ACT-R Cognitive Framework (Anderson, 2007)




```
(p encode-letter
   =goal>
      isa        read-letters
      state      attend
   =visual>
      isa        text
      value      =letter1
   ?imaginal>
      buffer     empty
==>
   =goal>
      state      wait
   +imaginal>
      isa        array
      letter1    =letter1
)
```

The Cognitive Complexity Metric in ACT-R?

Process	Factor	Modules	Implementation
Chunking	Familiarity	Declarative	Repeated retrievals are faster
	Size	Visual	more code to encode
	Control Structures	Imaginal, Vocal	mental iteration, boolean exps
	Boolean Expressions	Visual, Declarative	visual/mental shortcuts
	Recognizability	Visual, Imaginal	real code, build up representation
	Visual Structure	Visual	whitespace is significant
	Dependency Disruptions	Visual, Declarative, Manual	development env.
Tracing	Familiarity	Declarative	repeated retrievals, open tabs
	Localization	Visual	search strategy, external tools
	Ambiguity	Declarative	partial matching (variable name)
	Spatial Distance	Visual, Manual	what is “distance”?
	Level of Cueing	Visual	whitespace again, but less sensitive

Questions?