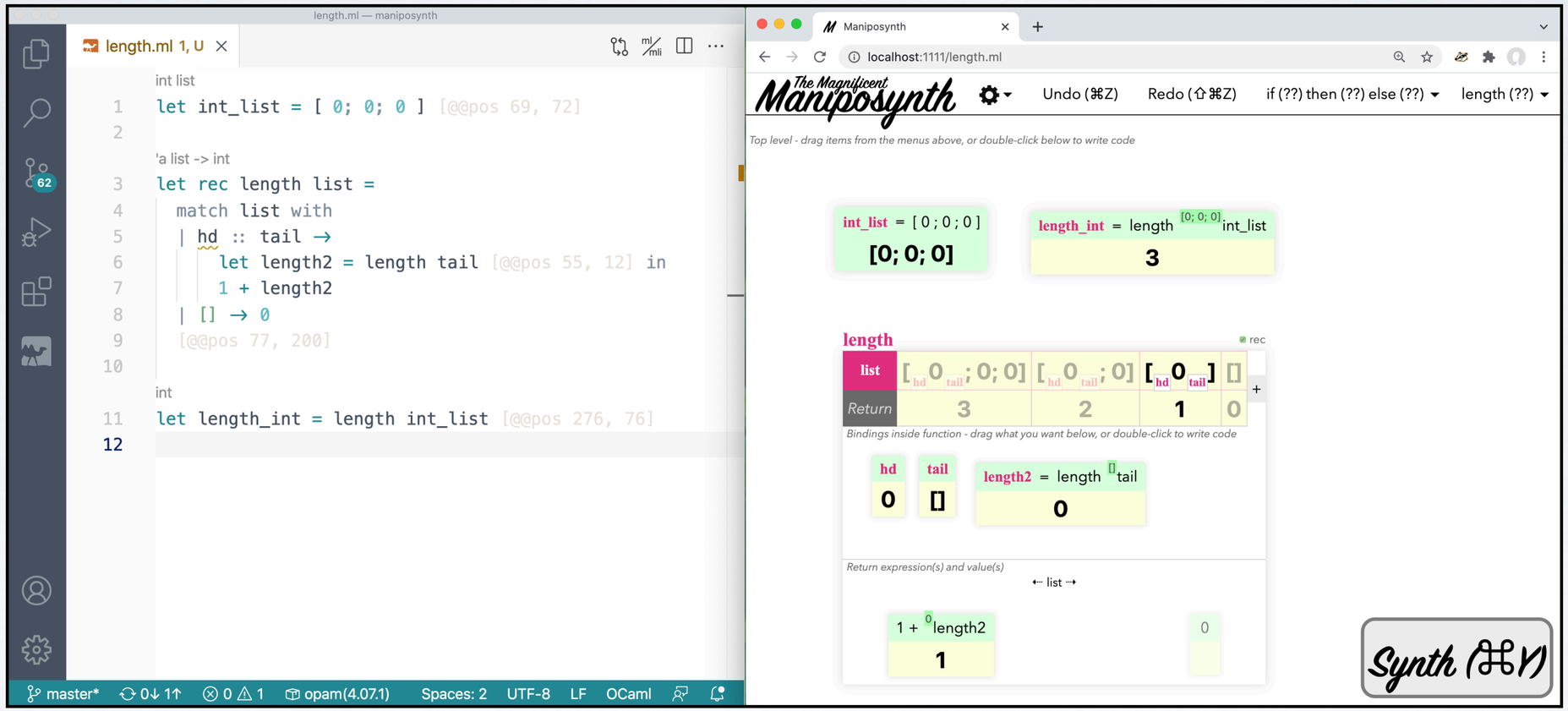
The Magnificent Maniposynth

Bimodal Tangible Functional Programming

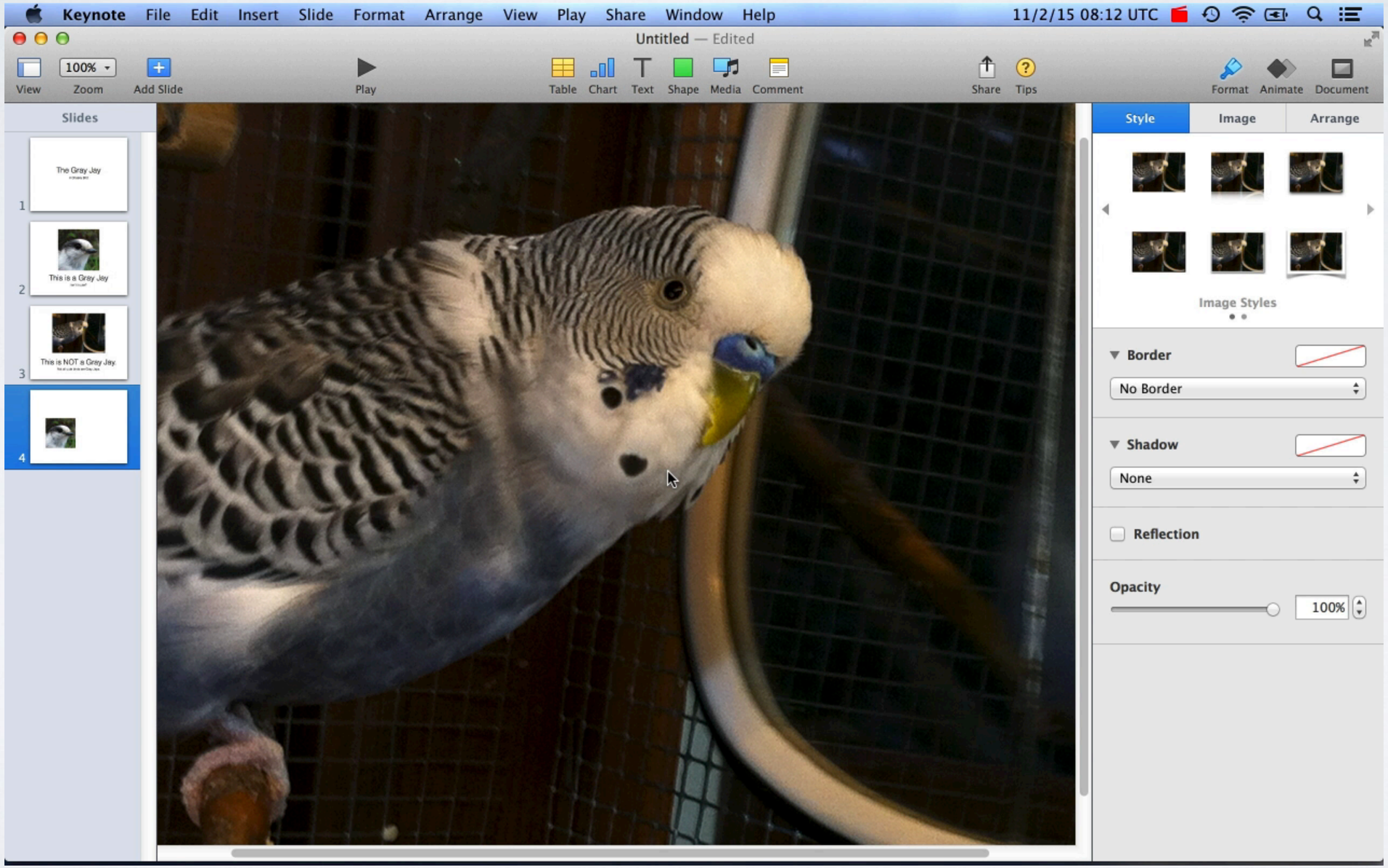


Brian Hempel and Ravi Chugh

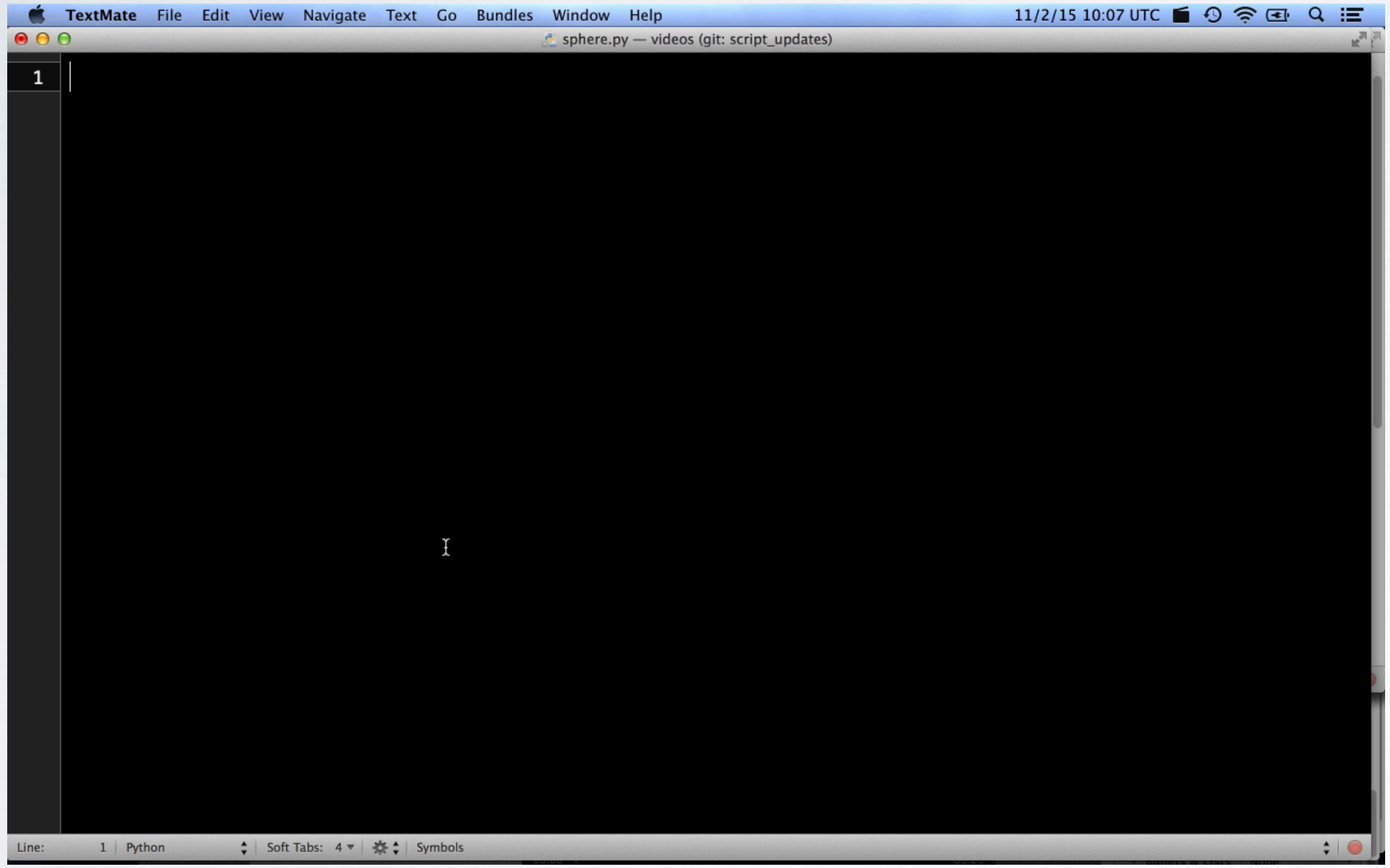
THE UNIVERSITY OF CHICAGO

ECOOP
30 June 2022

Direct Manipulation UI

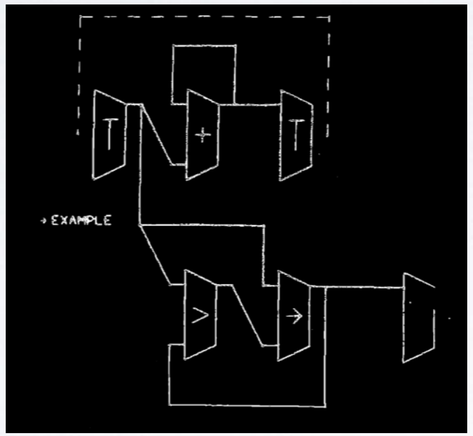


Why not D.M. for programming?



D.M. the **AST**…

Nodes-and-wires



The On-line Graphical Specification of Computer Procedures
W. Sutherland (1966)

Blocks

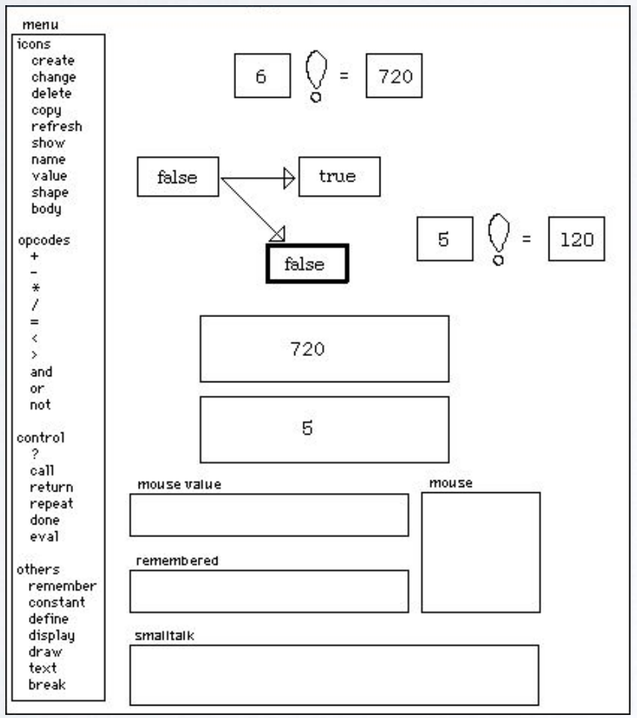
Scratch
Resnick et al. (2009)

…but those are **expressions** not output **values**

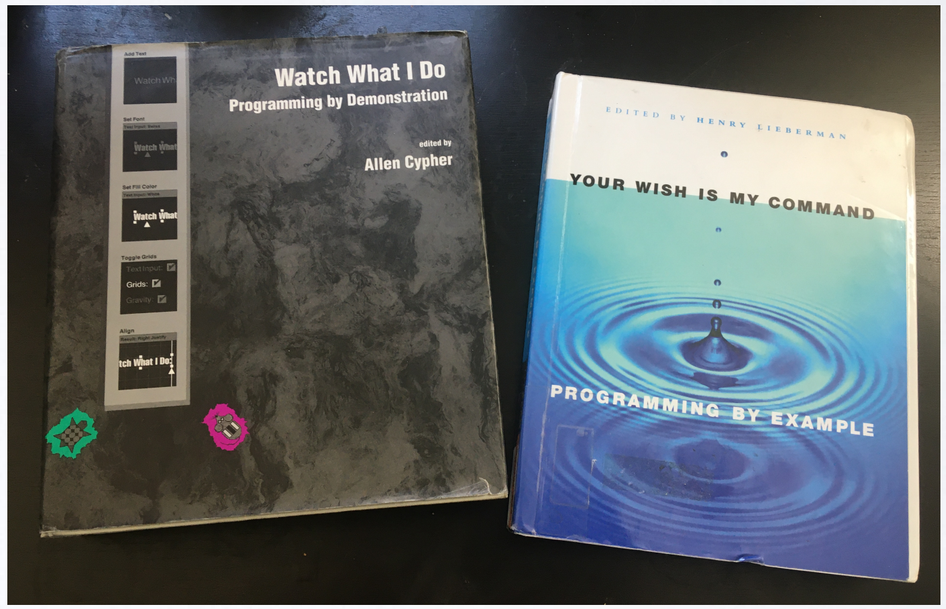
D.M. the **values**…

Programming by Demonstration (PBD)

You give a step-by-step demonstration of what you want the computer to do.

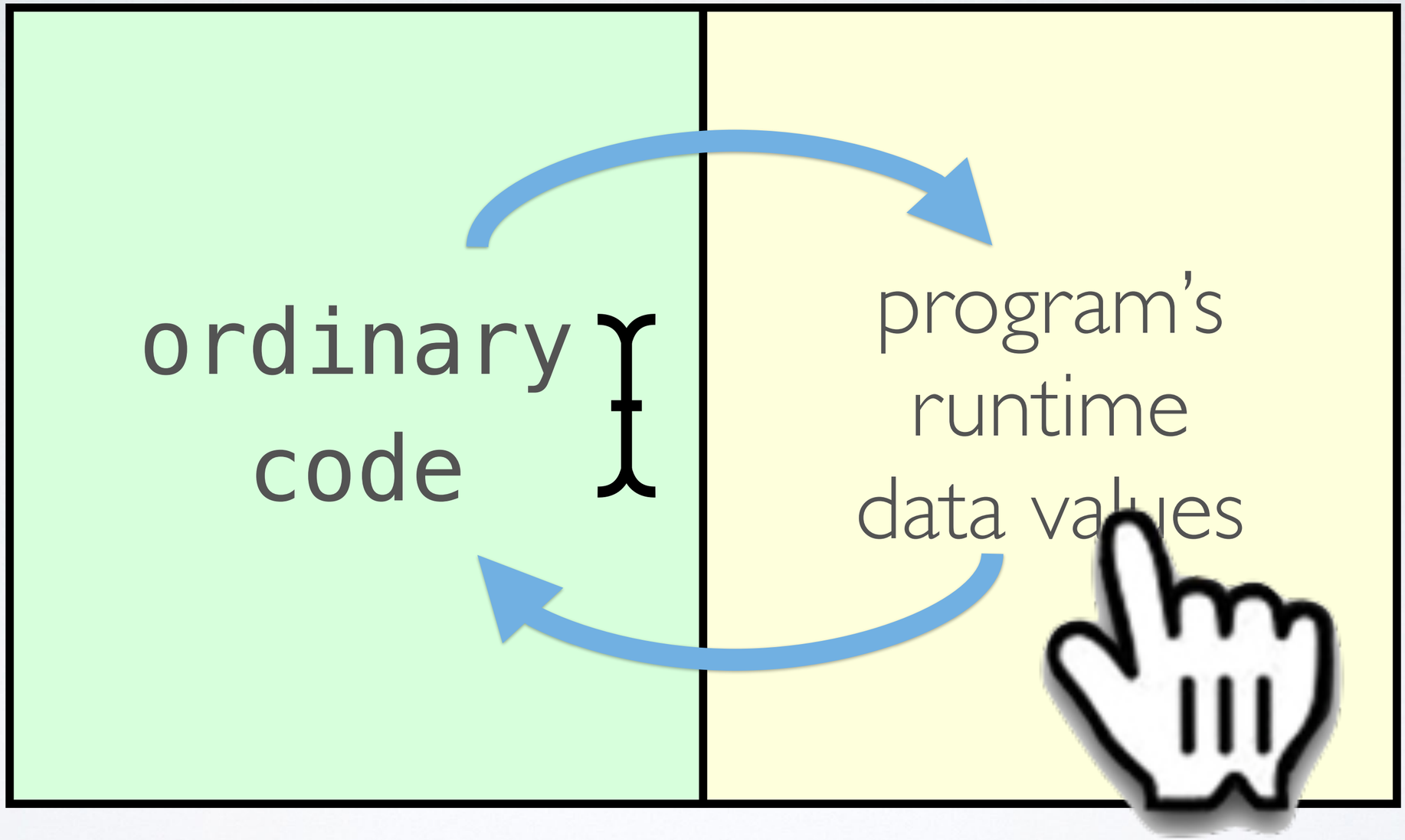


Pygmalion
Smith (1975)



Have you ever used PBD?

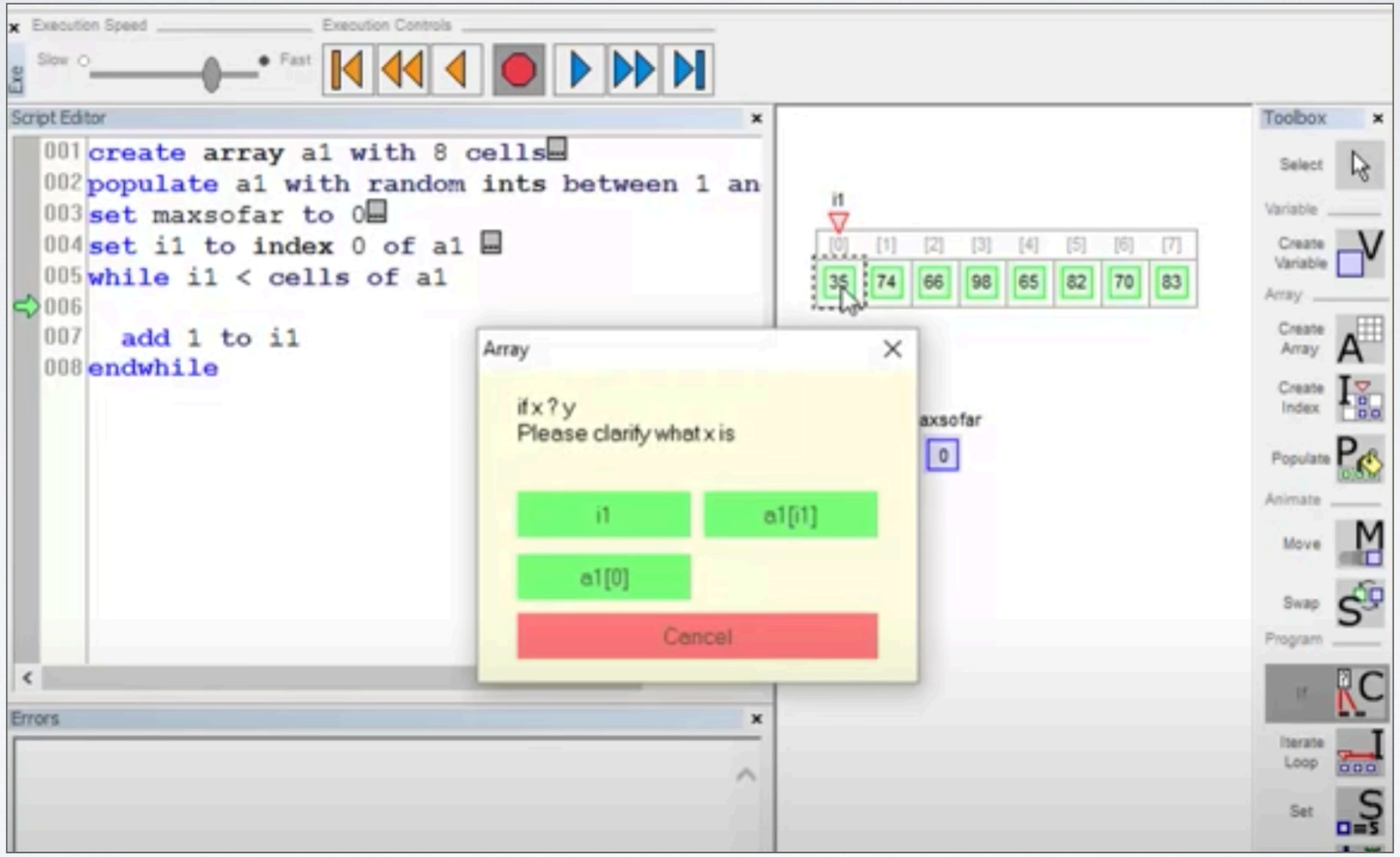
- **Domain-specific**
- **Rarely textual code**



Bimodal Programming

ALVIS Live!

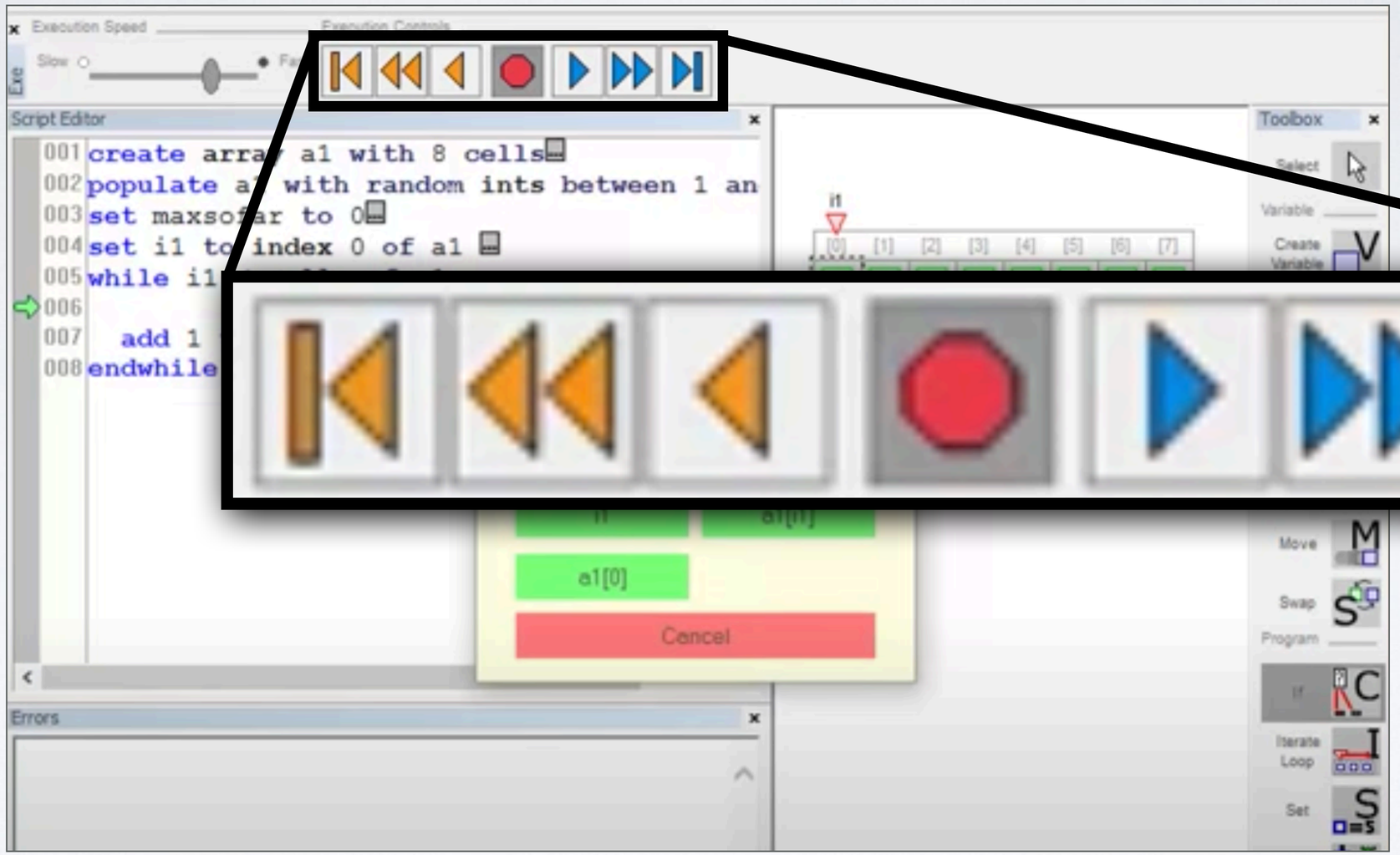
Hundhausen & Brown (2007)



Array algorithms (for education)

ALVIS Live!

Hundhausen & Brown (2007)

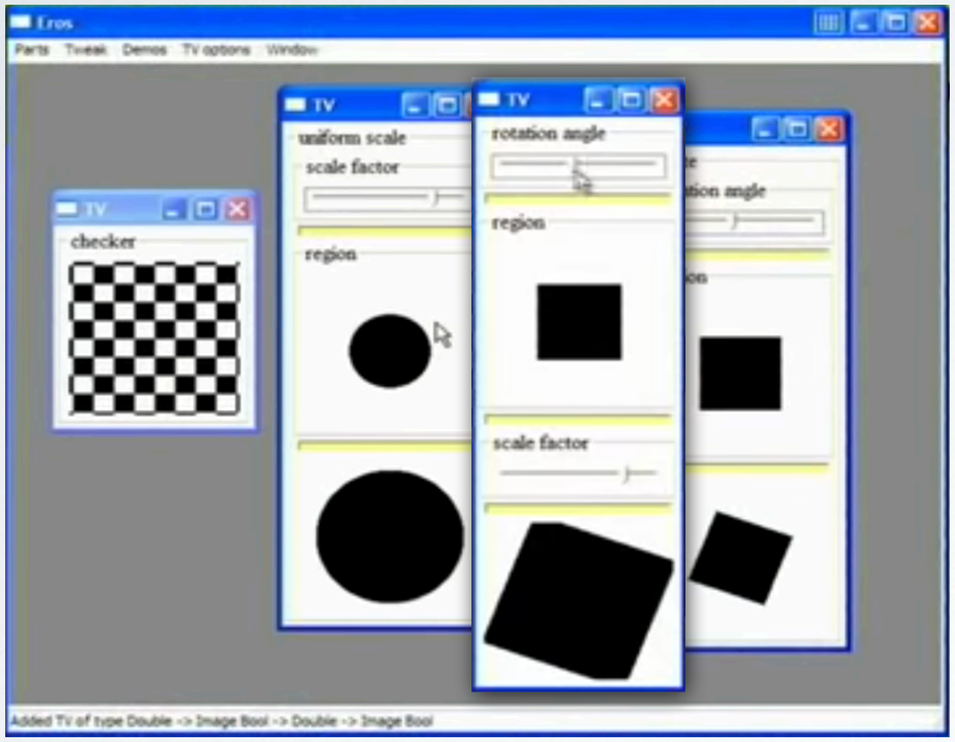


Array algorithms (for education)

Very **linear**: have to manage time.

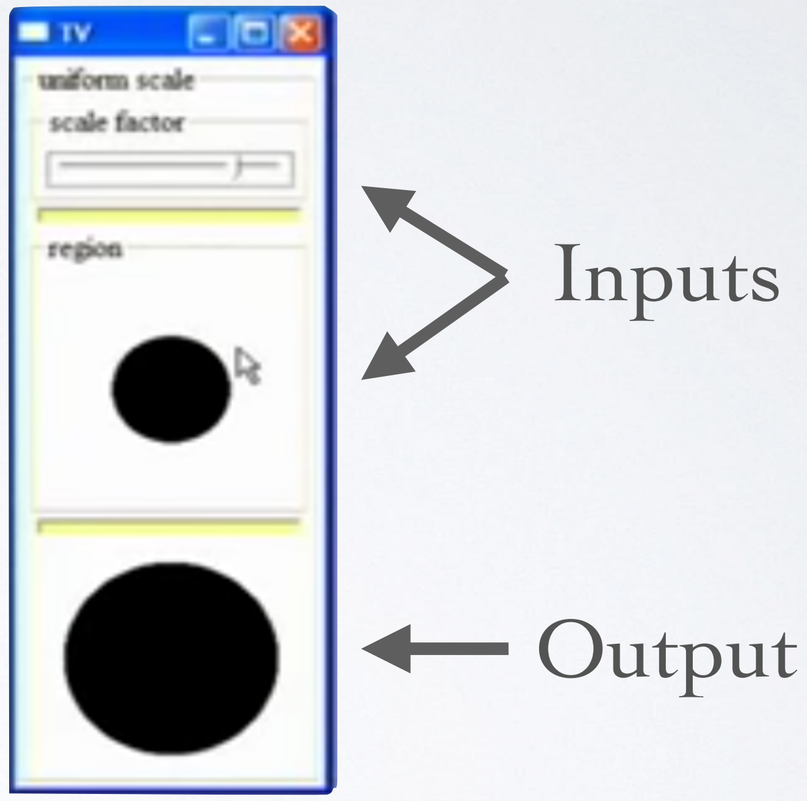
Tangible Functional Programming

Conal Elliott (2007)



Canvas of **tangible values**

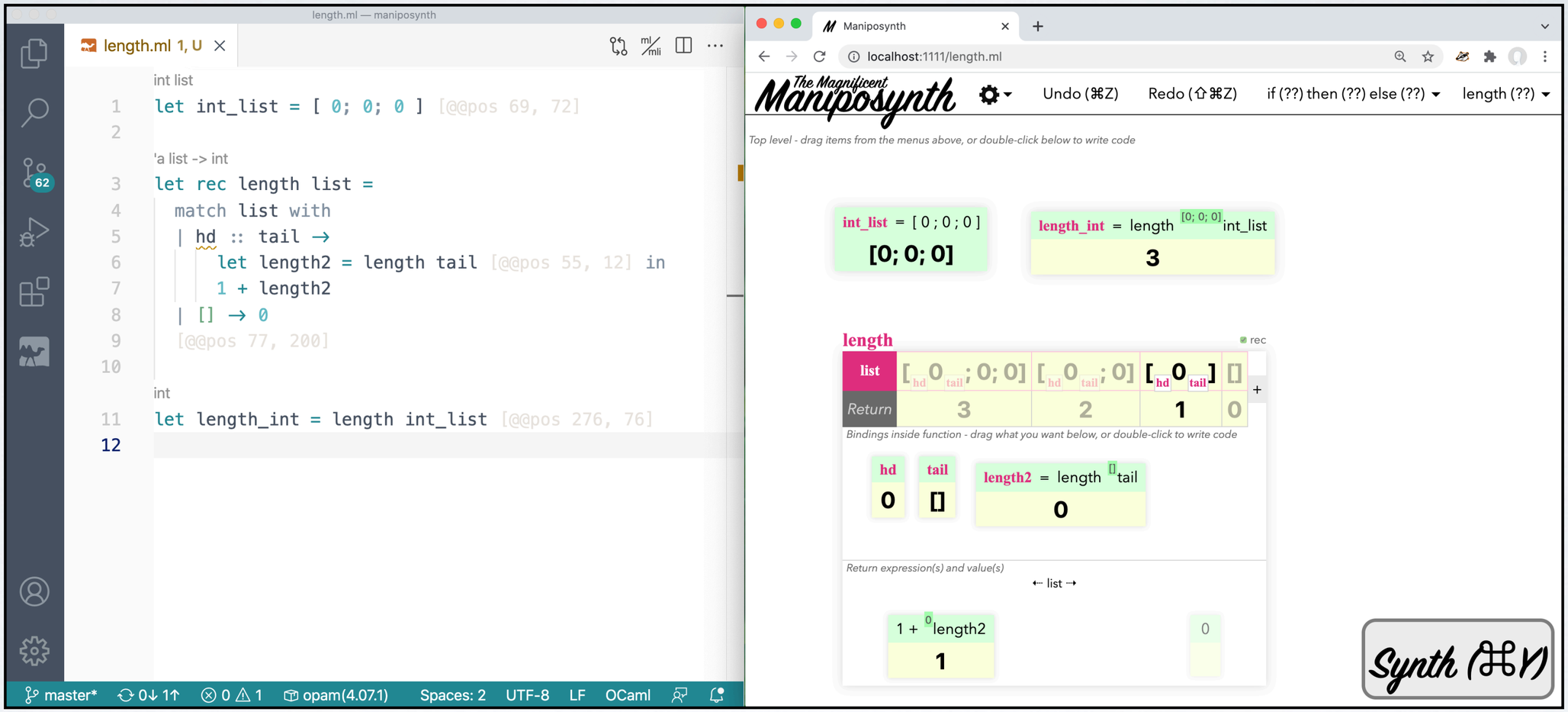
Tangible Value (TV)



Non-linear

Pure functional programming (no state) complements **non-linear** editing because, without state, one need not manage **time**.

Goals: Non-linear + Bimodal + Synthesis



Direct **Manip**ulation + **Synth**esis = The Magnificent Maniposynth

The Magnificent Maniposynth

- **Goals**
- Demo
- Implementation
- Evaluation
- Future Work & Conclusion

The Magnificent Maniposynth

- Goals
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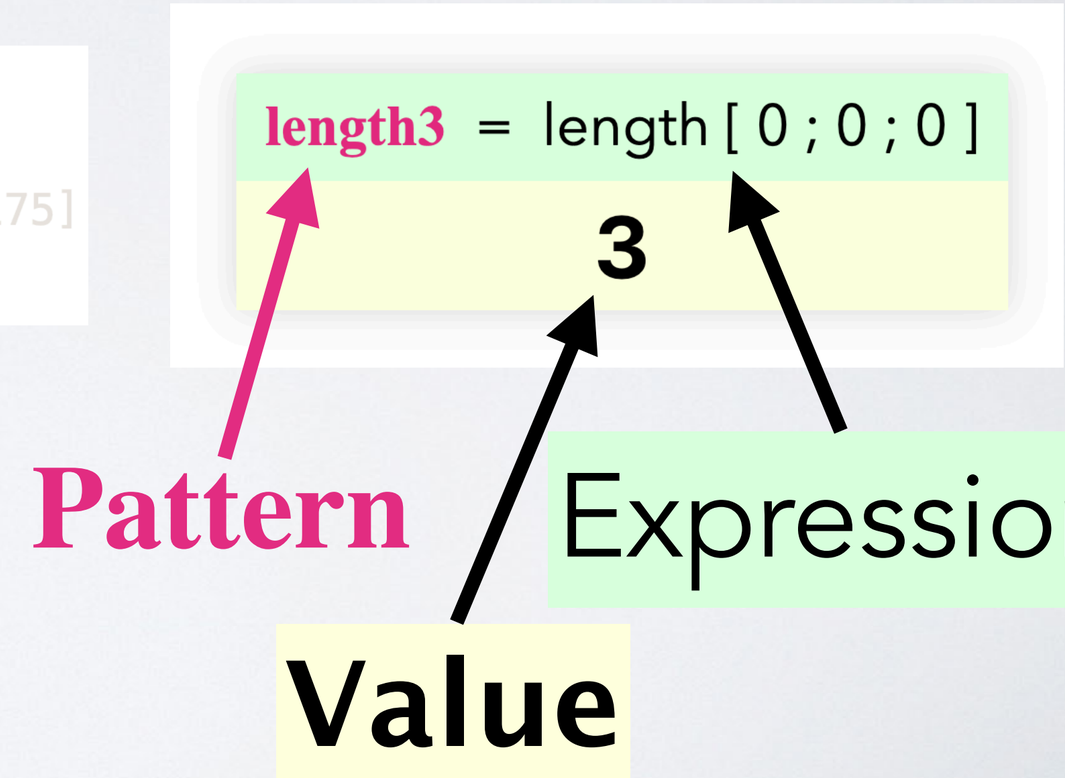
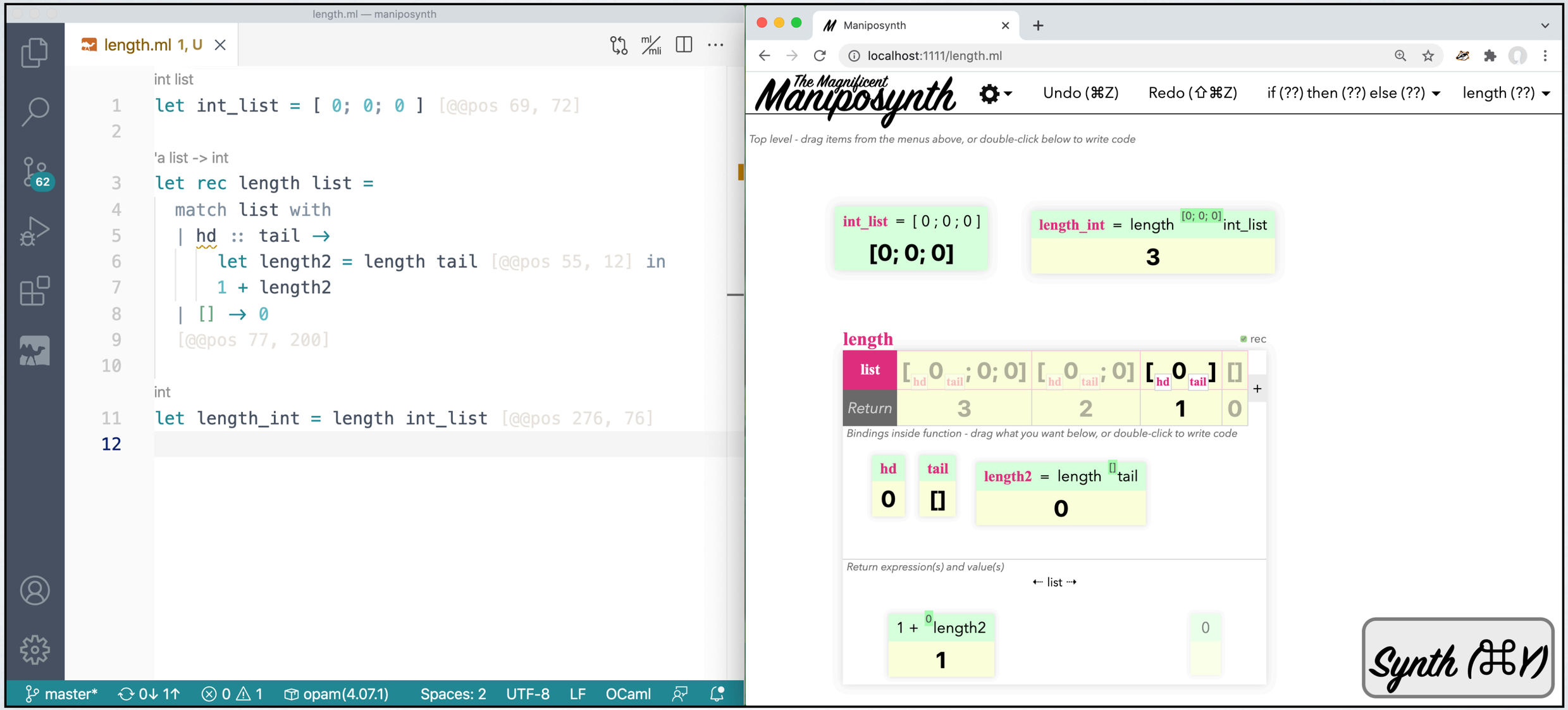
Tangible Values in Maniposynth

1 let-binding = 1 TV (Roughly)

```
4
    int
5   let length3 = length [ 0; 0; 0 ] [@@pos 405, 175]
6
```

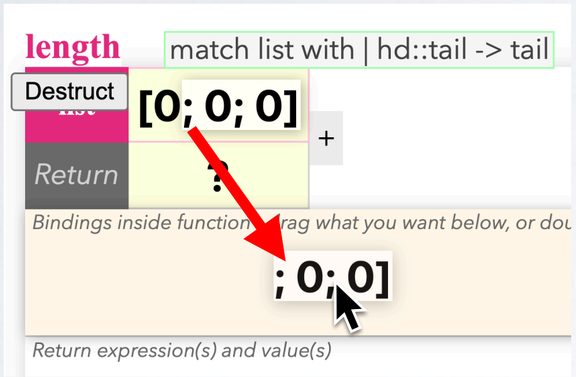


Demo: List Length

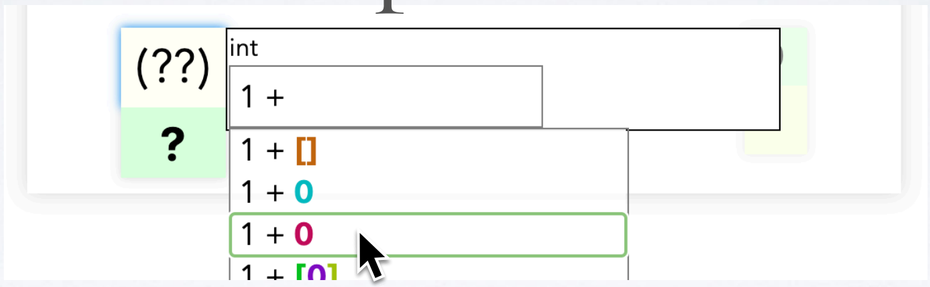


Demo: List Length

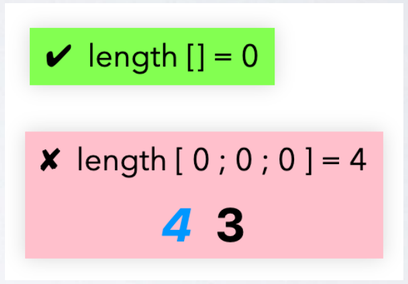
Drag to extract



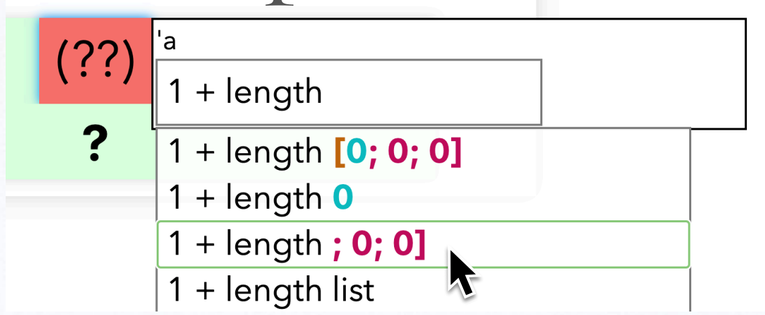
Autocomplete to **value**



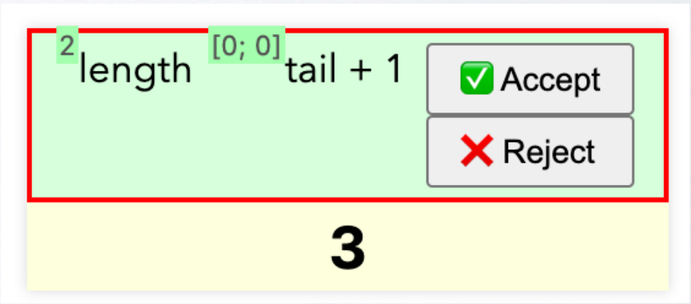
Assertions



Autocomplete to extract



Synthesis

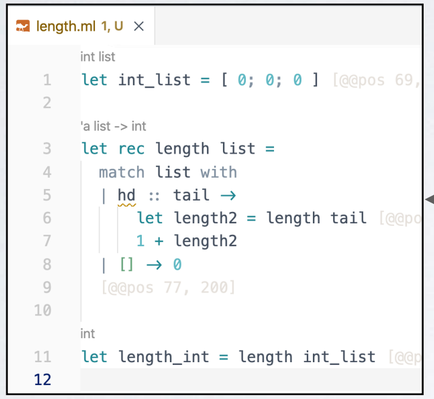


The Magnificent Manipposynth

- Goals
- Demo
- **Implementation**
  - **Interpreter**
  - **Binding reordering**
  - **Synthesizer**
- Evaluation
- Future Work & Conclusion

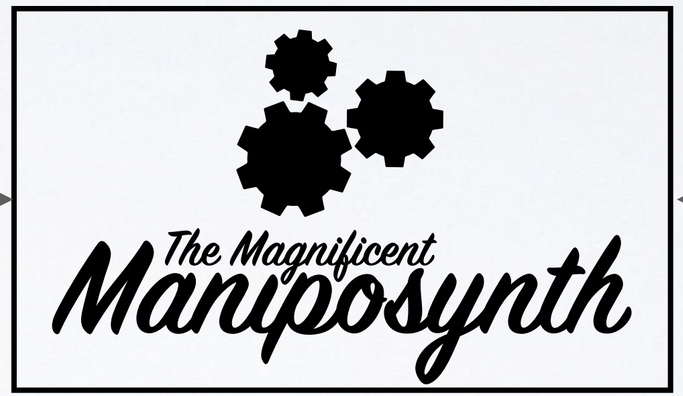
Architecture

Editor



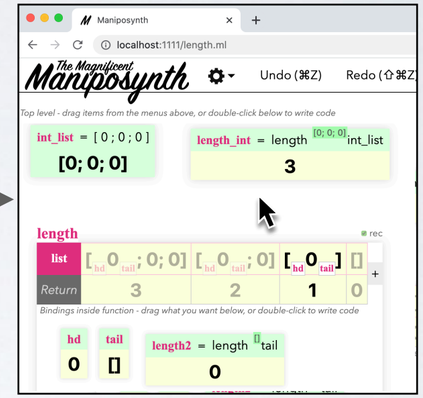
Code File

Webserver



~8600 OCaml LOC

Browser



~2000 JS LOC

Code is
"ground truth"

Server runs code
and renders HTML

Browser polls
for changes
or tells server
to do an action

Interpreter

- Adapted the interpreter from Camlboot [Courant et al. 2020]
  (Couldn't just modify the standard OCaml tools because the OCaml compiler performs type erasure—can't log the value when expression is at polymorphic type!)
- On each execution step, log:

```
(exp/pat, call frame num, val, env)
```

- For live display, show value at that exp/pat with the current call frame num

Binding reordering

2D canvas is unordered, let-bindings in code are automatically reordered to bring items into scope.

Requirement: All names at the same “indentation level” must be unique.

```
let a = 1

let c () =
  let x = (a, b, c, d) in
  let a = 0 in
  x

let b = 2
```

?

```
let b = 2

let rec c () =
  let a = 0 in
  let d = (??) in
  let x = (a, b, c, d) in
  x
```

Synthesizer

```
'a -> 'b
let length list = (??)

let () = assert (length [ 0; 0; 0 ] = 3)
```

- No big ideas, just want it to work with
  (a) few examples,
  (b) no type annotations, and
  (c) produce quality results
  even with the Pervasives functions in scope (e.g., addition, subtraction, etc).
- Type-directed, inspired by Myth (Osera and Zdancewic 2015)
- With a probabilistic context-free grammar (PCFG)

$$
\begin{array}{rrll}
\textbf{Expressions} & e & ::= & {}^{52\%}x \\
 & & \mid & {}^{20\%}e_1\ \overline{e_i} \\
 & & \mid & {}^{10\%}\textbf{fun}\ x \to e \\
 & & \mid & {}^{8.1\%}ctor \\
 & & \mid & {}^{6.6\%}c \\
 & & \mid & {}^{1.9\%}\textbf{match}\ e_1\ \textbf{with}\ \overline{C... \to\ e_i} \\
 & & \mid & {}^{1.3\%}\textbf{if}\ e_1\ \textbf{then}\ e_2\ \textbf{else}\ e_3
\end{array}
$$

$$
\begin{array}{rrll}
\textbf{Names} & x & ::= & {}^{73\%}localName \mid {}^{27\%}pervasivesName \\
\textbf{Local Names} & localName & ::= & {}^{31\%}MostRecentlyIntroduced \\
 & & \mid & {}^{20\%}2ndMostRecentlyIntroduced \\
 & & \mid & {}^{11\%}3rdMostRecentlyIntroduced \\
 & & \mid & ...\text{etc}...
\end{array}
$$

- More in paper and preprint appendix

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Two Evaluations

1. An expert (me) implemented 38 examples from the first lessons of a functional data structures course (IN2347 Functional Data Structures, Technische Universität München)

2. Exploratory user study with two professional OCaml programmers

   Goal: **qualitative** insights. What is or is not working?

Example Implementation Results

Function	LOC	Asserts	Time	Mouse	Keybd	Un/Re/Del	TypeErr	Crash
nat_plus	5		0.8	6	5			
nat_minus	8		1.9	6	11			
nat_mult	9		1.4	8	6			
nat_exp	13		2.1	9	6			
nat_factorial	13		1.6	8	4			
nat_map_sumi	10		2.6	11	5		1	
count	9		1.9	9	11			
length	4		0.3	1	7			
snoc	8	1	2.4	8	12	2		
reverse	8		1.5	4	9			
nat_list_max	17		4.6	23	21			
nat_list_sum	13		1.1	9	4			
fold	9		3.2	14	6			
shuffles	14		14.5	25	28	2		
contains	9		2.2	10	13	1		
distinct	16		2.4	9	11	2		
foldl	10	1	1.5	10	6		1	
foldr	8	1	1.8	10	5			
slice	12	3	9.8	19	22	4		
append	8	1	1.4	7	9			
sort_by	21	3	6.2	17	29			
quickselect	13	1	13.1	19	38	1	1	
sort	16	3	5.6	11	32	2		
ltree_inorder	12	1	2.9	7	20	1	1	
ltree_fold	13	1	3.1	13	13			
ltree_mirror	11	1	4.4	12	6		1	1
bst_contains	14	3	6.6	11	32	1		
bst_contains2	17	5	10.4	20	41	2		
btree_join	34	2	61.7	82	64	51		2
bst_delete	36	2	14.4	31	24	4		
bstd_valid	29	3	32.2	63	100	4	1	
bstd_insert	18	2	8.0	38	23	3		
bstd_count	21	1	7.6	15	32	1		
bst_in_range	31	3	9.3	23	39	3		
btree_enum	29	3	19.2	31	51	6	3	
btree_height	15	1	1.9	11	14			
btree_pretty	14	1	3.7	4	21		4	
btree_same_shape	19	1	8.1	14	34	7		
Total	**566**	**44**	**277.6**	**628**	**814**	**97**	**13**	**3**

Fastest, 0.3min

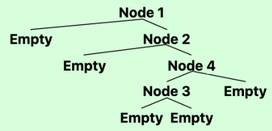
Slowest, 62min

4.5 hours, 3 tool crashes, but success!

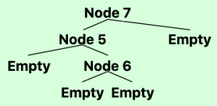
```
type 'a btree = | Node of 'a btree * 'a * 'a btree | Empty
```

Top level - drag items from the menus above, or double-click below to write code

tree1 = Node (Empty , 1 , Node (Empty , 2 , Node (Node (Empty , 3 , Empty), 4 , Empty)))



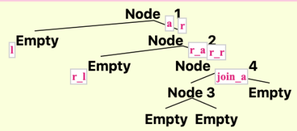
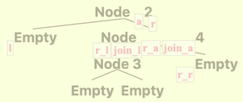
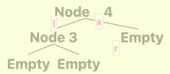
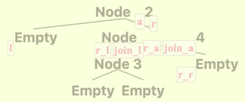
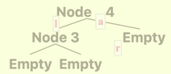
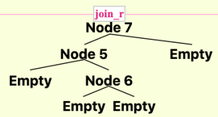
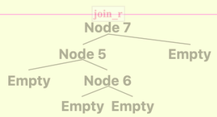
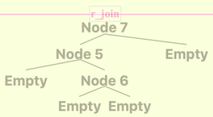
tree2 = Node (Node (Empty , 5 , Node (Empty , 6 , Empty)), 7 , Empty)



✔ btree_join tree1 tree2 = Node (Node (Empty , 1 , Node (Empty , 2 , Node (Empty , 3 , Empty))), 4 , Node (Node (Empty , 5 , Node (Empty , 6 , Empty)), 7 , Empty))

✔ btree_join tree1 Empty = Node (Node (Empty , 1 , Node (Empty , 2 , Node (Empty , 3 , Empty))), 4 , Empty)

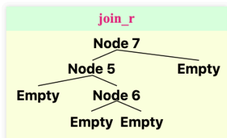
btree_join rec

tree1				...2 more...			Empty
tree2				...2 more...	join_r Empty	r_join Empty	Empty
Return	**Node (Node (Empty, 1, Node (Empty, 2, Node (Empty, 3, Empty))), 4 , Node (Node (Empty, 5, Node (Empty, 6, Empty)), 7, Empty))**	**Node (Node (Empty, 2, Node (Empty, 3, Empty)), 4, Node (Node (Empty, 5, Node (Empty, 6, Empty)), 7, Empty))**	**Node (Node (Empty, 3, Empty), 4, Node (Node (Empty, 5, Node (Empty, 6, Empty)), 7, Empty))**	...2 more...	**Node (Node (Empty, 2, Node (Empty, 3, Empty)) , 4, Empty)**	**Node (Node (Empty, 3, Empty), 4, Empty)**	Empty

\+

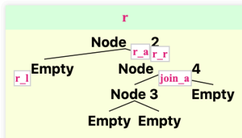
Bindings inside function - drag what you want below, or double-click to write code

join_r

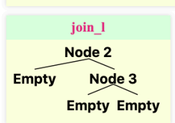


join_a 4

r



join_l



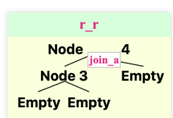
l Empty

a 1

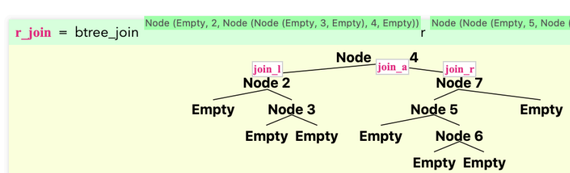
r_l Empty

r_a 2

r_r



r_join = btree_join Node (Empty, 2, Node (Node (Empty, 3, Empty), 4, Empty)) r Node (Node (Empty, 5, Node (Empty, 6, Empty)), 7, Empty) tree2



Return expression(s) and value(s)

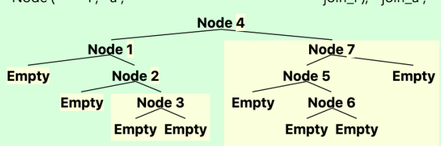
← tree1 →

← r →

← r_join →

Node (l , a , tree2)

Node (Node (Empty, 1, Node (Empty, 2, Node (Empty, 3, Empty))) l , 1 a , Node (Empty, 2, Node (Empty, 3, Empty)) join_l), 4 join_a , Node (Node (Empty, 5, Node (Empty, 6, Empty)), 7, Empty) join_r)



failwith "impossible"

tree2

Observations

Could hide the code

No trouble with binding order
(some trouble with nested match order)

Value-oriented vs. **expression**-oriented thinking

```
length3 = length [ 0 ; 0 ; 0 ]
```

```
3
```

Despite trying to place attention on values…

…often thought only about expressions.

User Study

- 2 participants x 3 sessions x 2 hours each
- 5 and 11 years of professional OCaml experience
- Ran Maniposynth on their own computers alongside Vim
- Participants attempted exercises with varying amounts of guidance from facilitator
- Goal: **qualitative** insights

Observations from User Study

- Positive about non-linearity: “fits a lot more with how I like to write code” (P1)
- Too many colors, too few labels
- Even in session three, both participants occasionally still needed guidance from the facilitator
- Writing assertions was not a problem: both wanted to do so, unprompted
- Synthesis only produced useful results 16% of the time, but participants were not bothered when it did not
- (More in paper)

Expression-oriented vs.

Value-oriented thinking

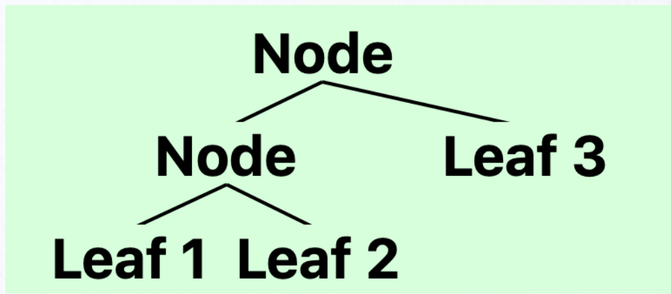
P2 didn't fully realize they were working with live values until *after* the first exercise.

P1 & facilitator stuck on a bug that was clear from looking at the live values

P2 was so used to reading

```
Node (Node (Leaf 1, Leaf 2), Leaf 3))
```

they were subtly repelled by beautified trees



The Magnificent Maniposynth

- Goals
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- Implementation
- **Evaluation**
- Future Work & Conclusion

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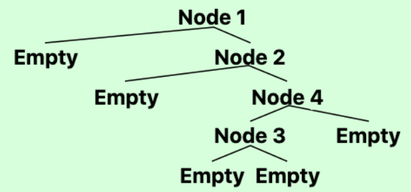
Future Work

More self-description in UI (Tooltips?)

Shrink large values

```
tree1 = Node (Empty , 1 , Node (Empty , 2 , Node (Node (Empty , 3 , Empty ), 4 , Empty )))
```



Encourage **value-oriented** thinking

- Display values instead of variable names?

List.mem 2 target [1; 2; 3] list

List.mem target 2 list [1; 2; 3]

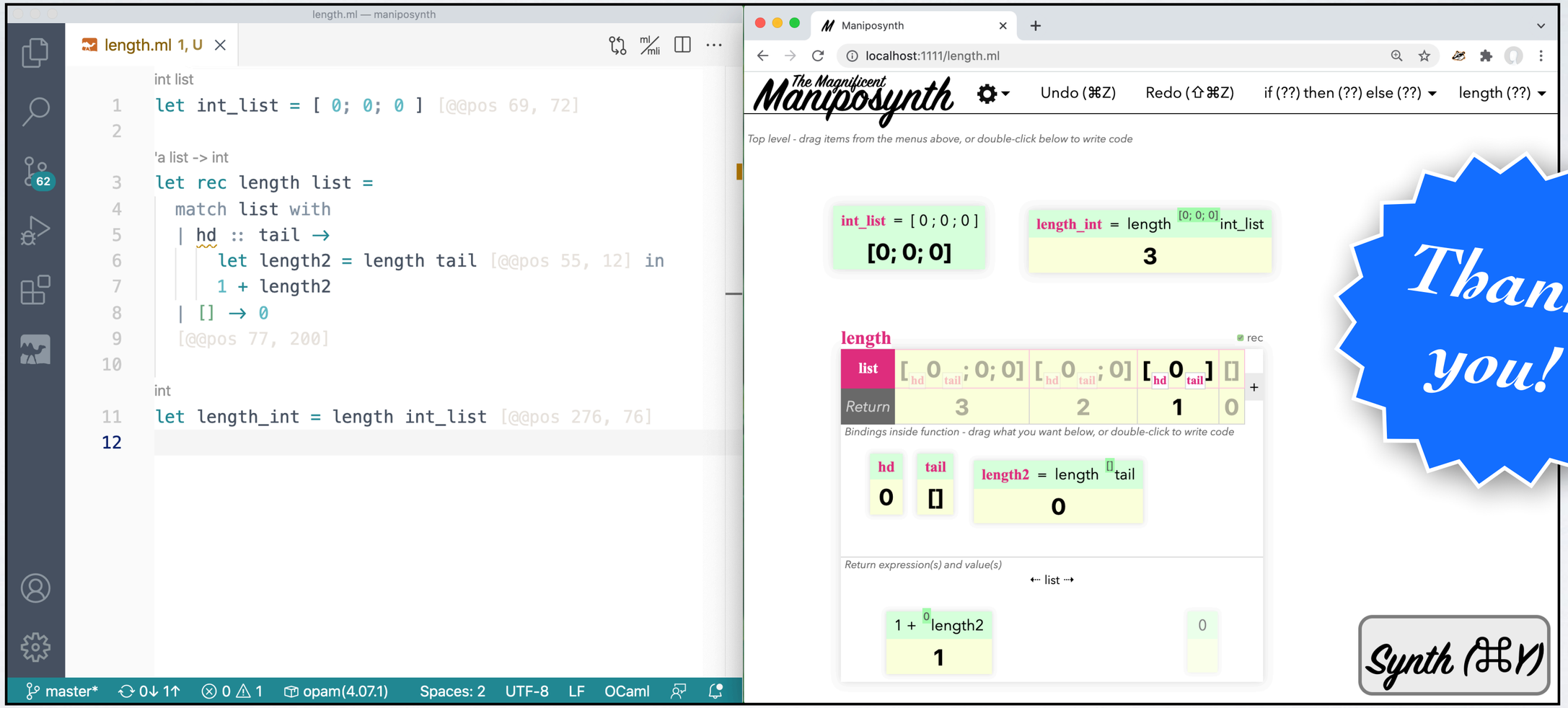
- More actions on values?

Conclusion

Yes, you can have a **graphical, non-linear** interface even when the program is **ordinary code**.

The Magnificent Maniposynth

Bimodal Tangible Functional Programming



Visit maniposynth.org for artifact and video