Incremental Interactive Computation

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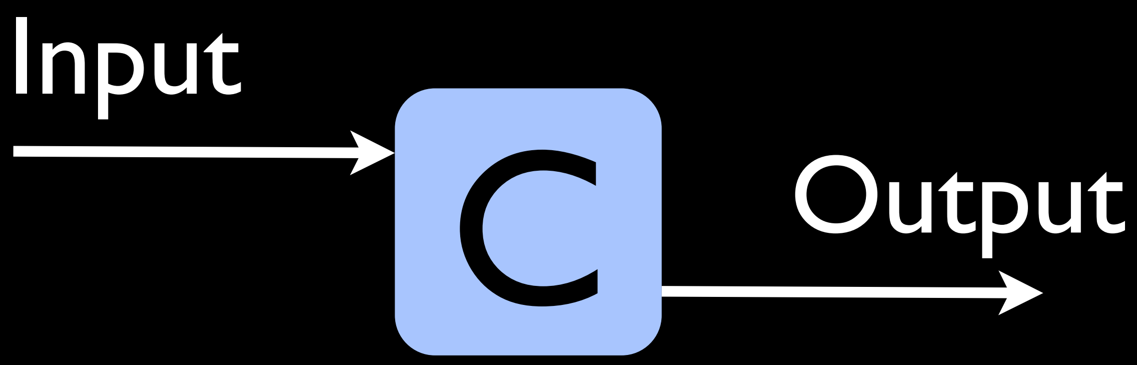
Batch Computation vs Interactive Computation

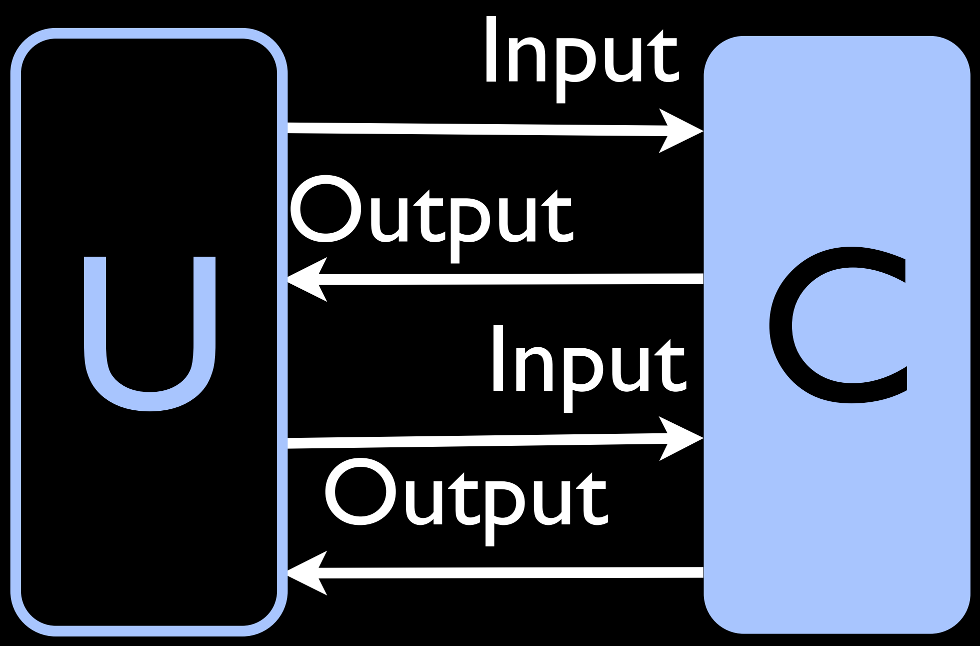
Batch Model

No time,
no dialogue

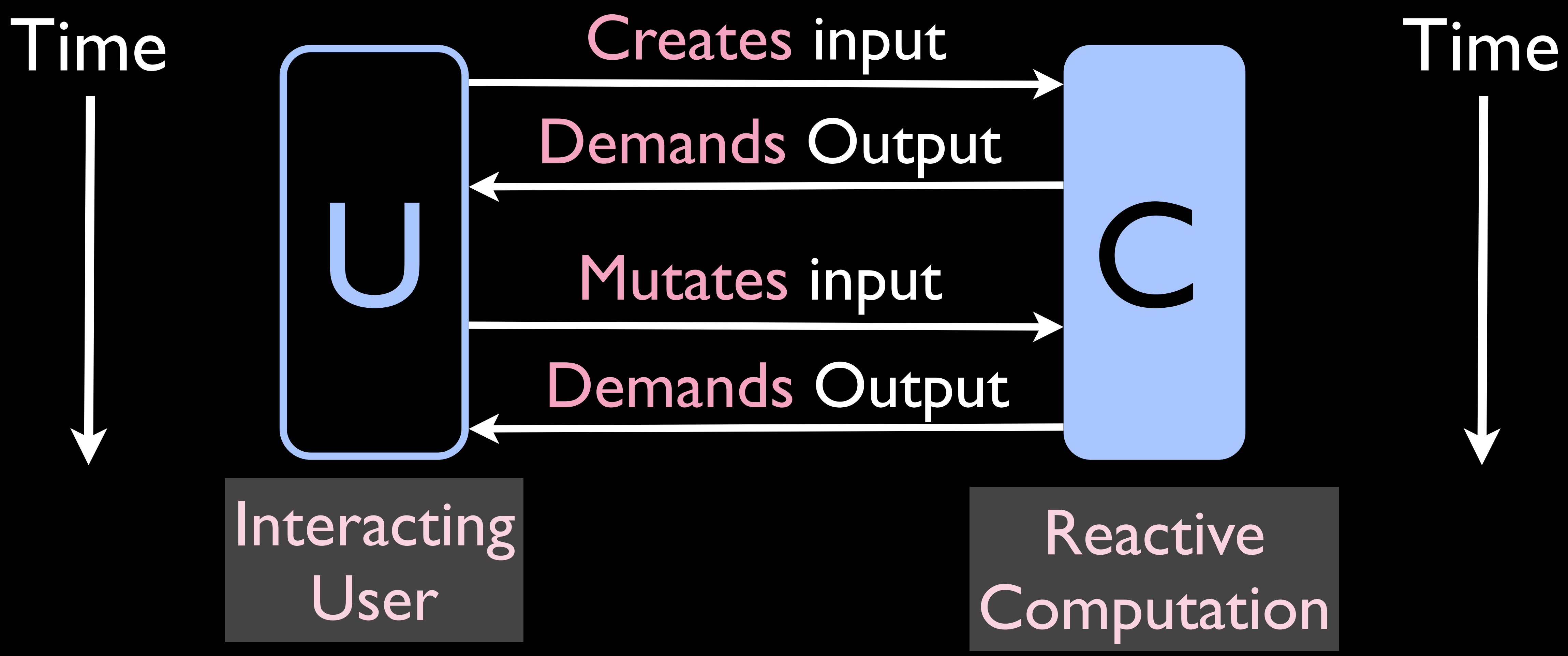


Interactive Model

Dialogue in time



Interaction is a Dialogue



Time

U

Creates input

Demands Output

Mutates input

Demands Output

C

Time

Interacting User

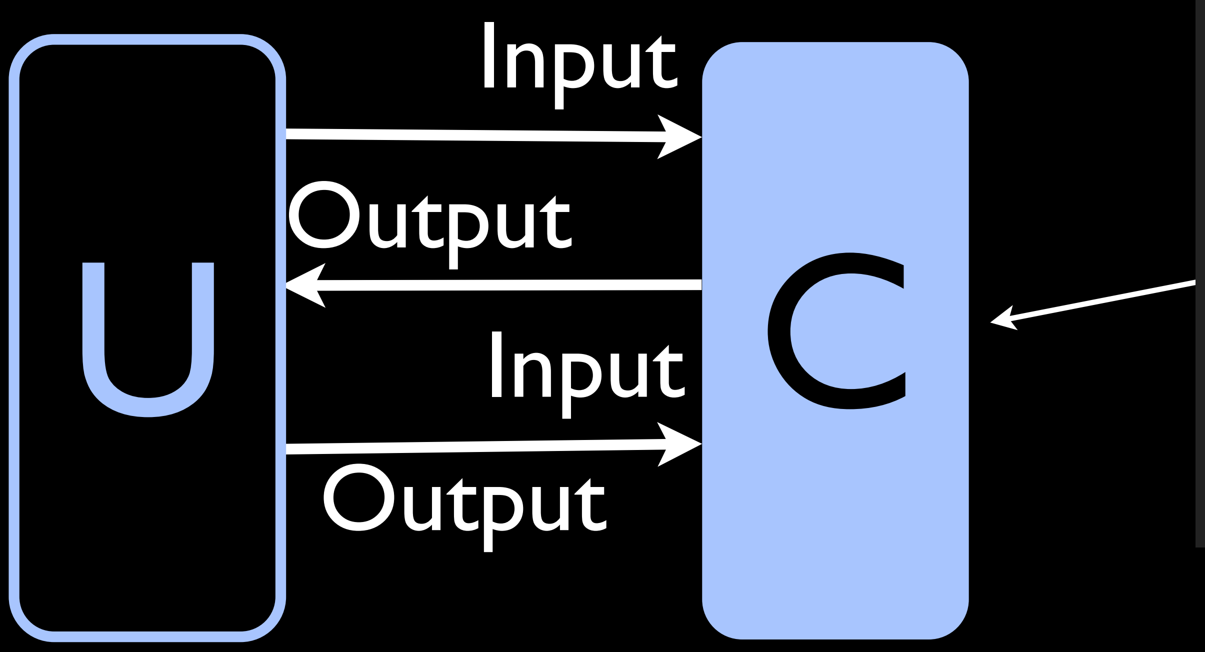
Reactive Computation

Elements of Interactive Dialogue

- User and system interact across time
- User mutates / changes input structure
- User demands / observes output structure
- The system maintains a correspondence between input and output structures
- I/O correspondence is computational

Incremental Interactive Computation

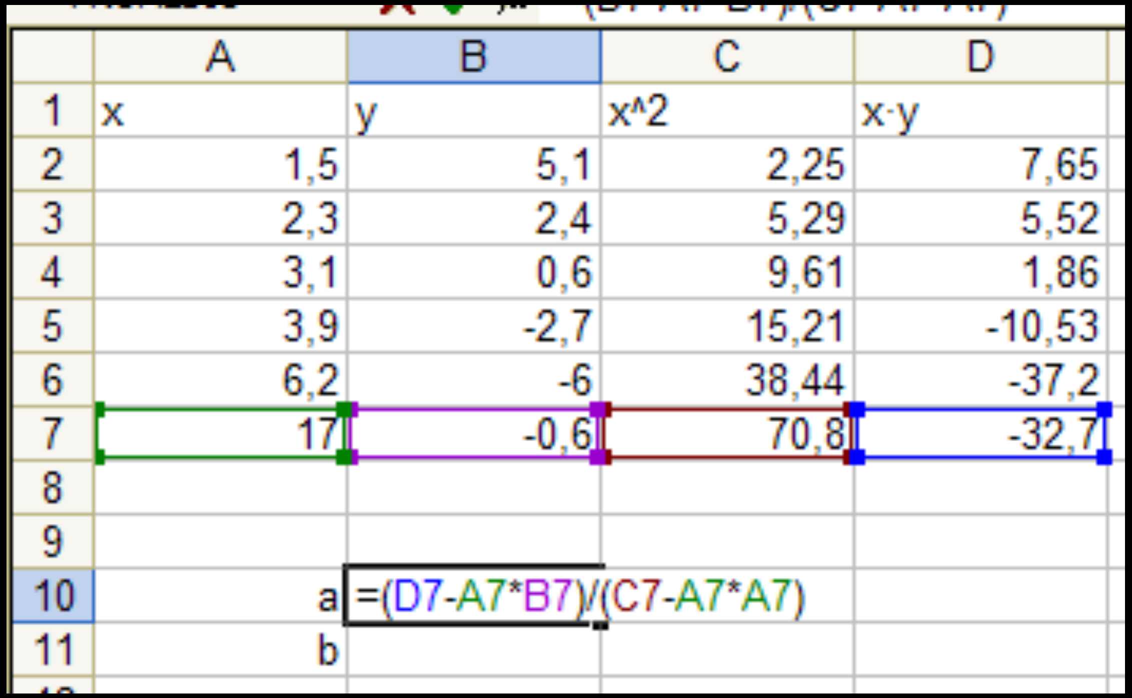
Incremental Interactive Computation



Claim: Interesting **interactive** systems consist of **incremental computations**

Example: Spreadsheets

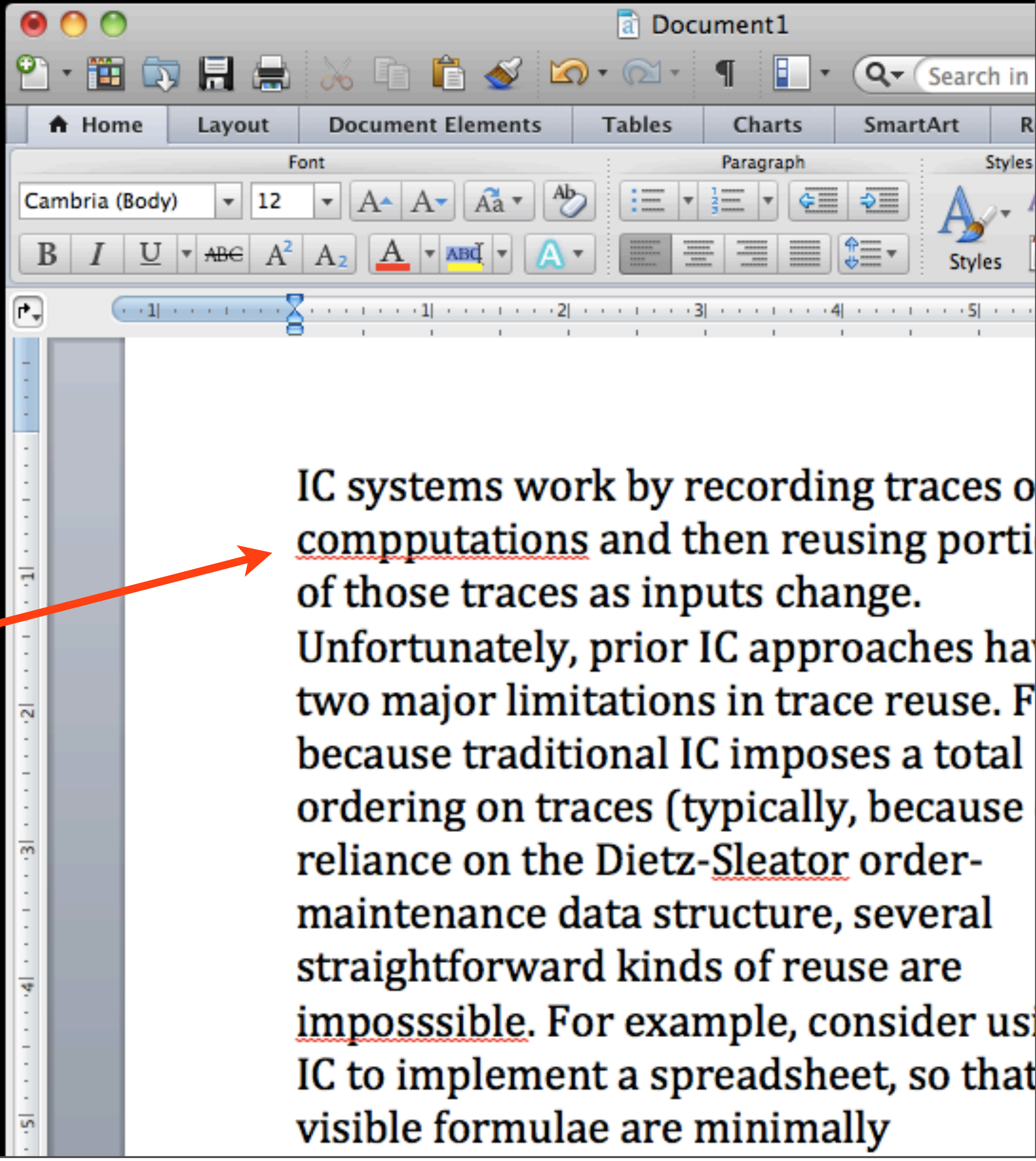
Input Structure	Cell Formulae
Incremental Computation	Formula evaluation
Output Structure	Cell values



	A	B	C	D
1	x	y	x^2	x·y
2	1,5	5,1	2,25	7,65
3	2,3	2,4	5,29	5,52
4	3,1	0,6	9,61	1,86
5	3,9	-2,7	15,21	-10,53
6	6,2	-6	38,44	-37,2
7	17	-0,6	70,8	-32,7
8				
9				
10	a	=(D7-A7*B7)/(C7-A7*A7)		
11	b			

Example: Word processing

Input Structure	Document Content
Incremental Computation	Spell-check each word
Output Structure	Highlight misspellings



IC systems work by recording traces o
compputations and then reusing porti
of those traces as inputs change.
Unfortunately, prior IC approaches ha
two major limitations in trace reuse. F
because traditional IC imposes a total
ordering on traces (typically, because
reliance on the Dietz-Sleator order-
maintenance data structure, several
straightforward kinds of reuse are
imposssible. For example, consider usi
IC to implement a spreadsheet, so that
visible formulae are minimally

Example: Programming

Input	Text file
Computation	Parse tokens
Output	AST

Input	AST
Computation	Lexical scoping
Output	Def/use edges

Input	AST + Def/use
Computation	Type inference
Output	Type errors

Computing Incrementally

1. Input changes are gradual

Full re-computation is often **redundant**

2. Output observation is limited

Full re-computation is often **overly eager**

Computing Incrementally

1. Input changes are gradual
2. Output observation is limited

Example: Spreadsheet	Cells change slowly
Example: Word processing	Document and dictionary both change slowly
Example: Programming	Program changes slowly

Computing Incrementally

1. Input changes are gradual
2. Output observation is limited

Example: Spreadsheet	One worksheet is active, others hidden
Example: Word processing	Viewport shows one or two pages
Example: Programming	Viewport shows one file, module or function

Adapton

Abstractions for Incremental Interaction

Current draft available here:

http://www.cs.umd.edu/~hammer/pldi2014/2014-adapton-tr.pdf

To appear at PLDI 2014!

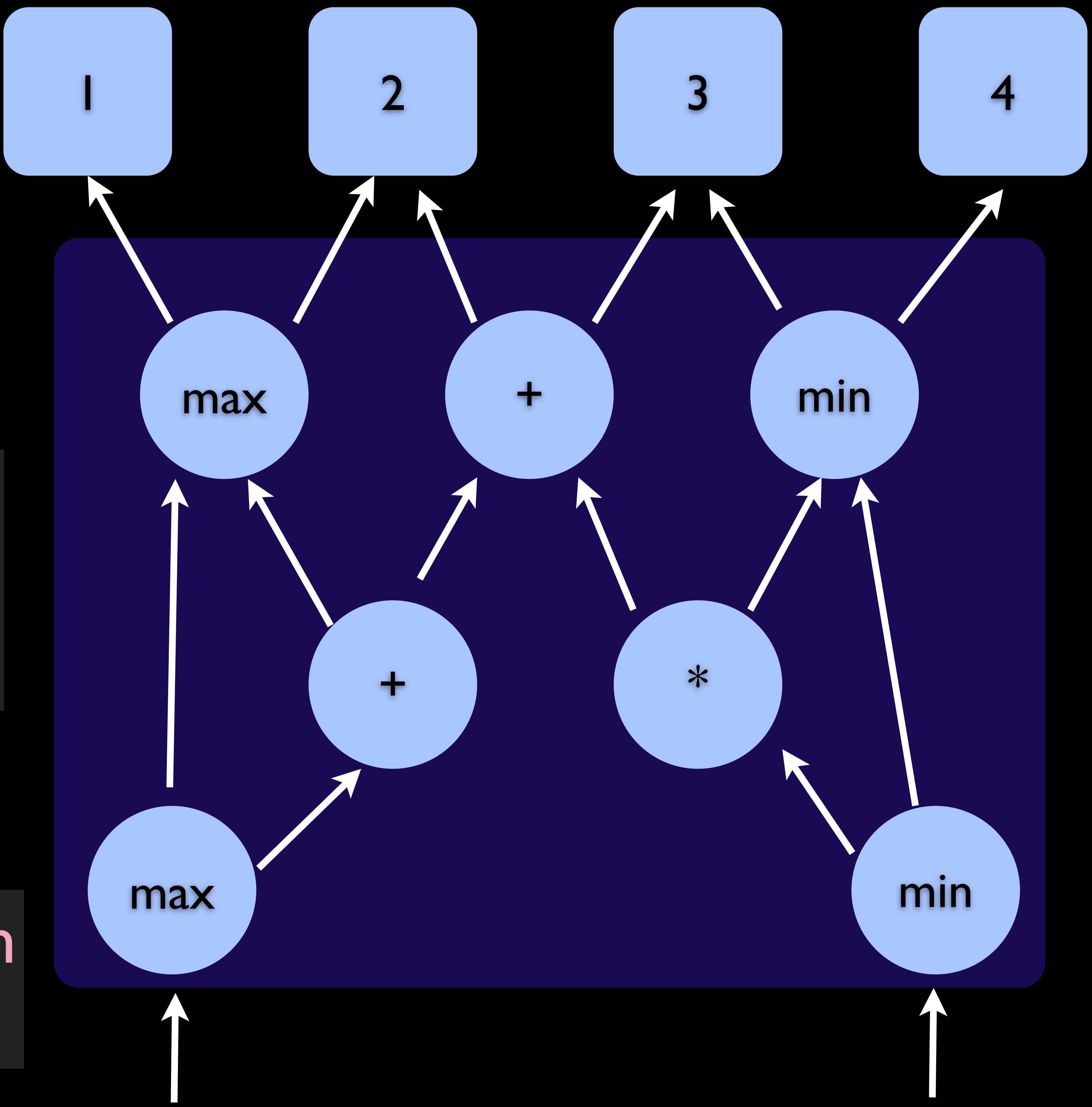
Adapton Programming Abstractions

- **Mutable references:**
  - Hold changing input structure
- **Lazy thunks:**
  - Demand-driven computations
  - Output structure

Mutable references

Incremental Computation (thunks)

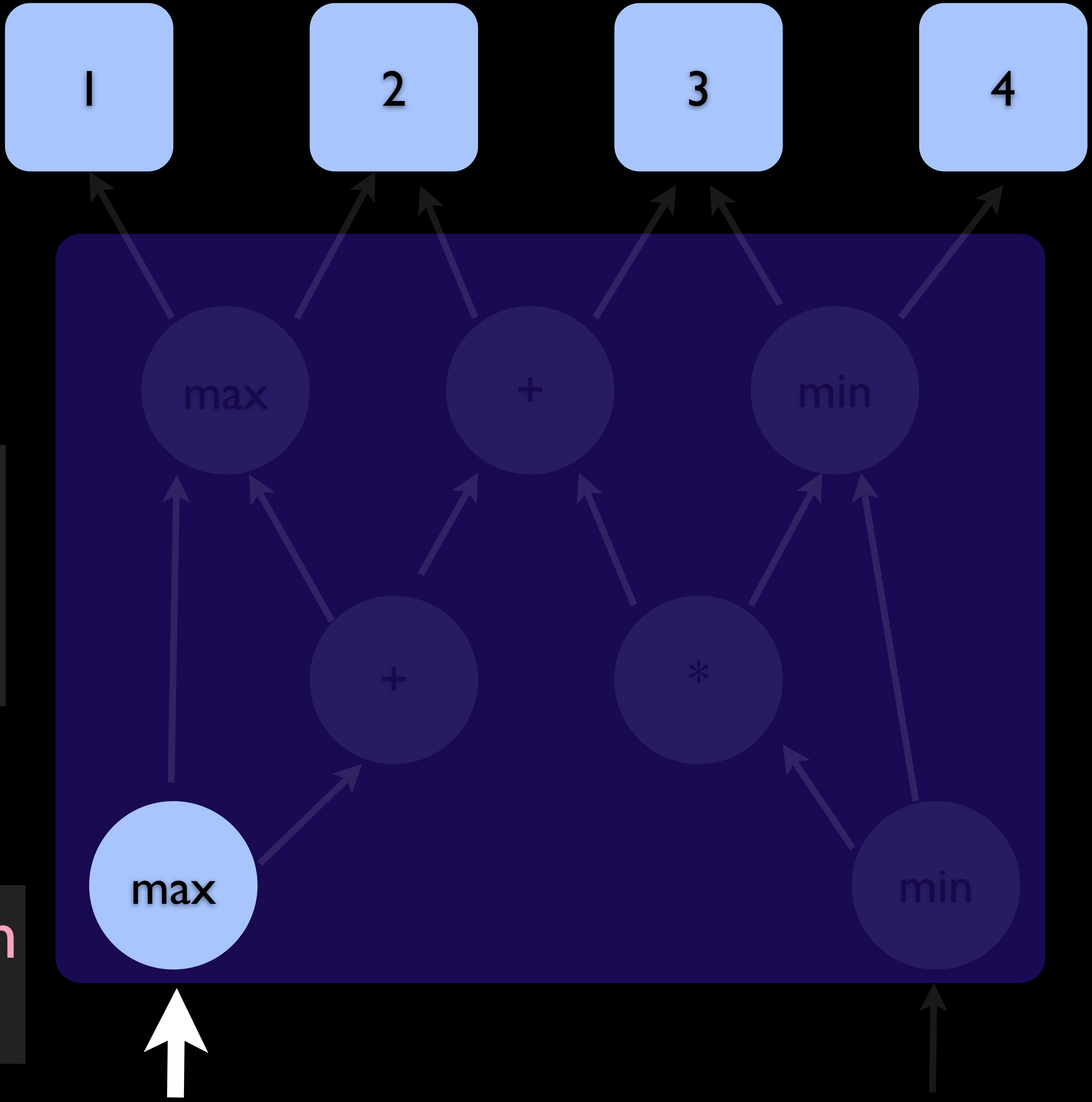
Demand-driven Outputs



Mutable references

Incremental Computation (thunks)

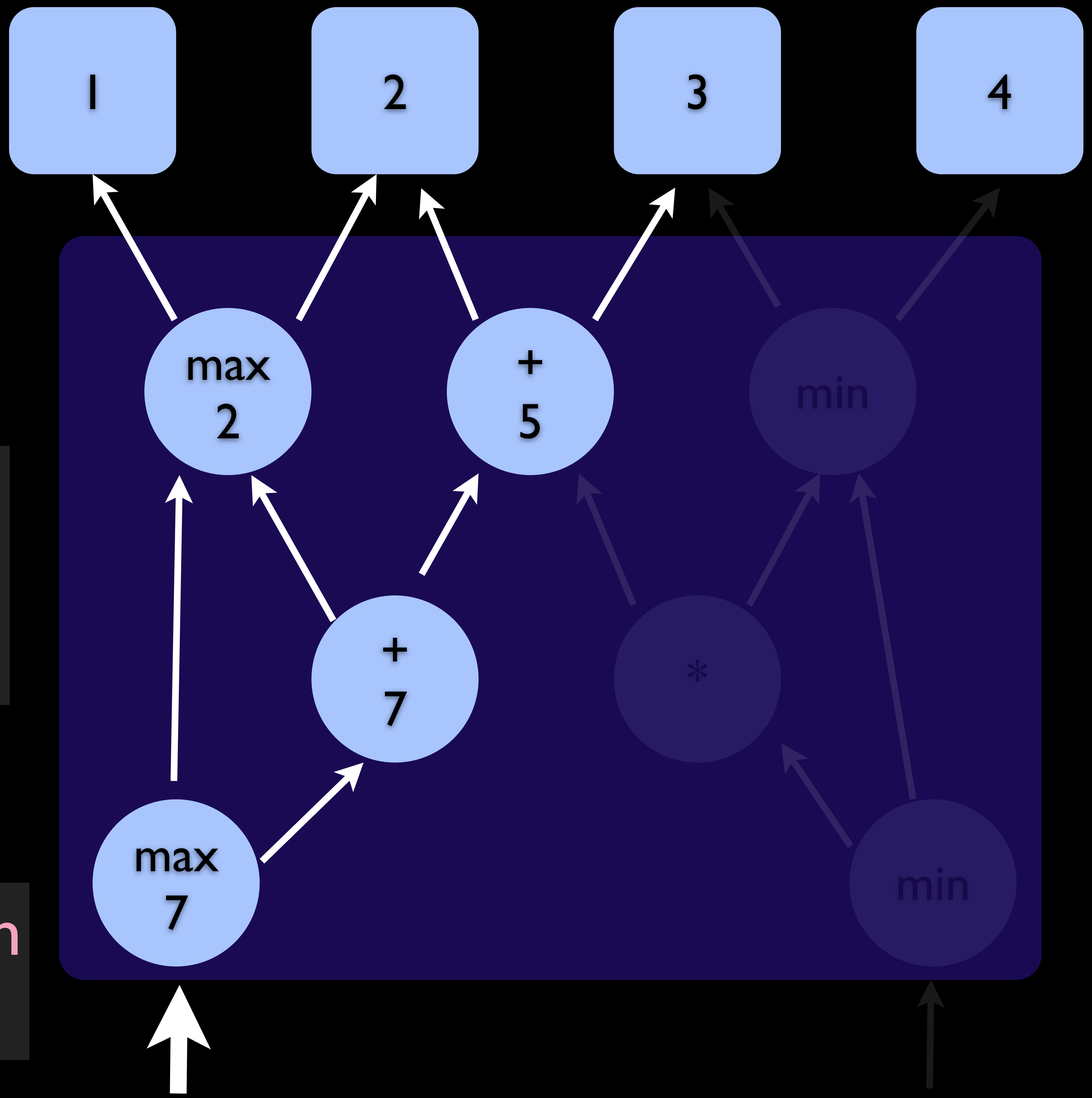
Demand-driven Outputs



Mutable references

Incremental Computation (thunks)

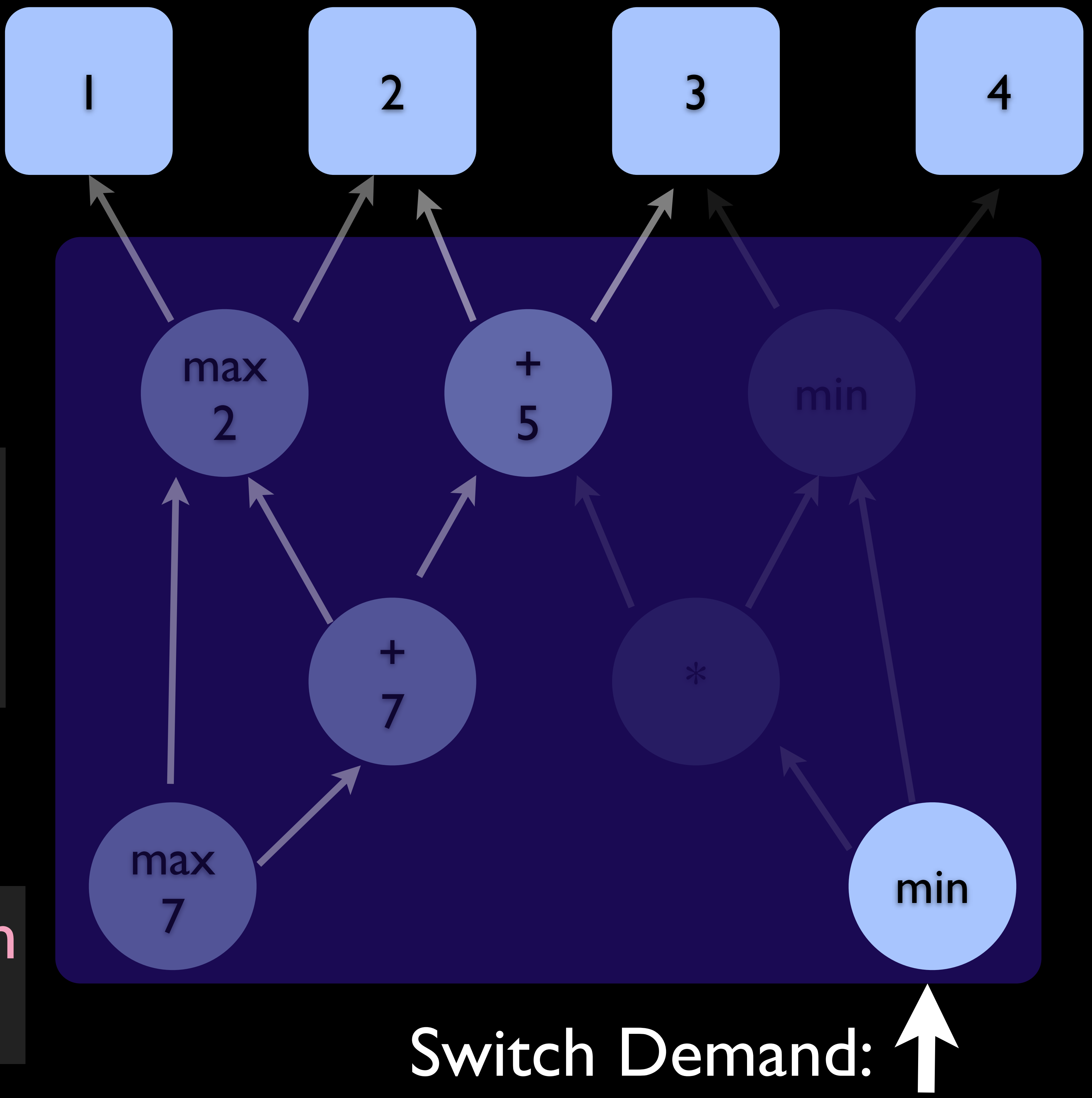
Demand-driven Outputs



Mutable references

Incremental Computation (thunks)

Demand-driven Outputs

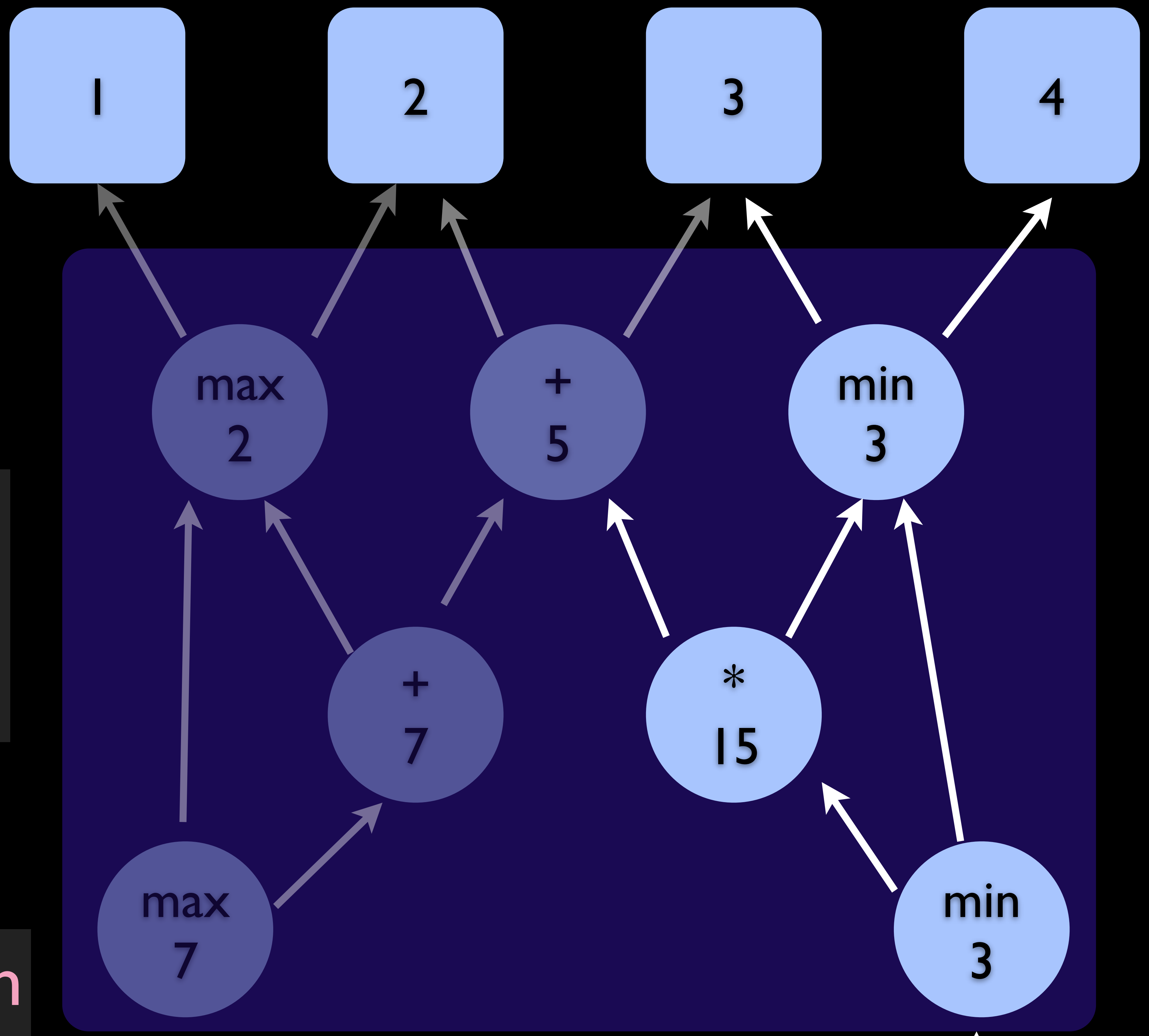


Switch Demand: ↑

Mutable references

Incremental Computation (thunks)

Demand-driven Outputs

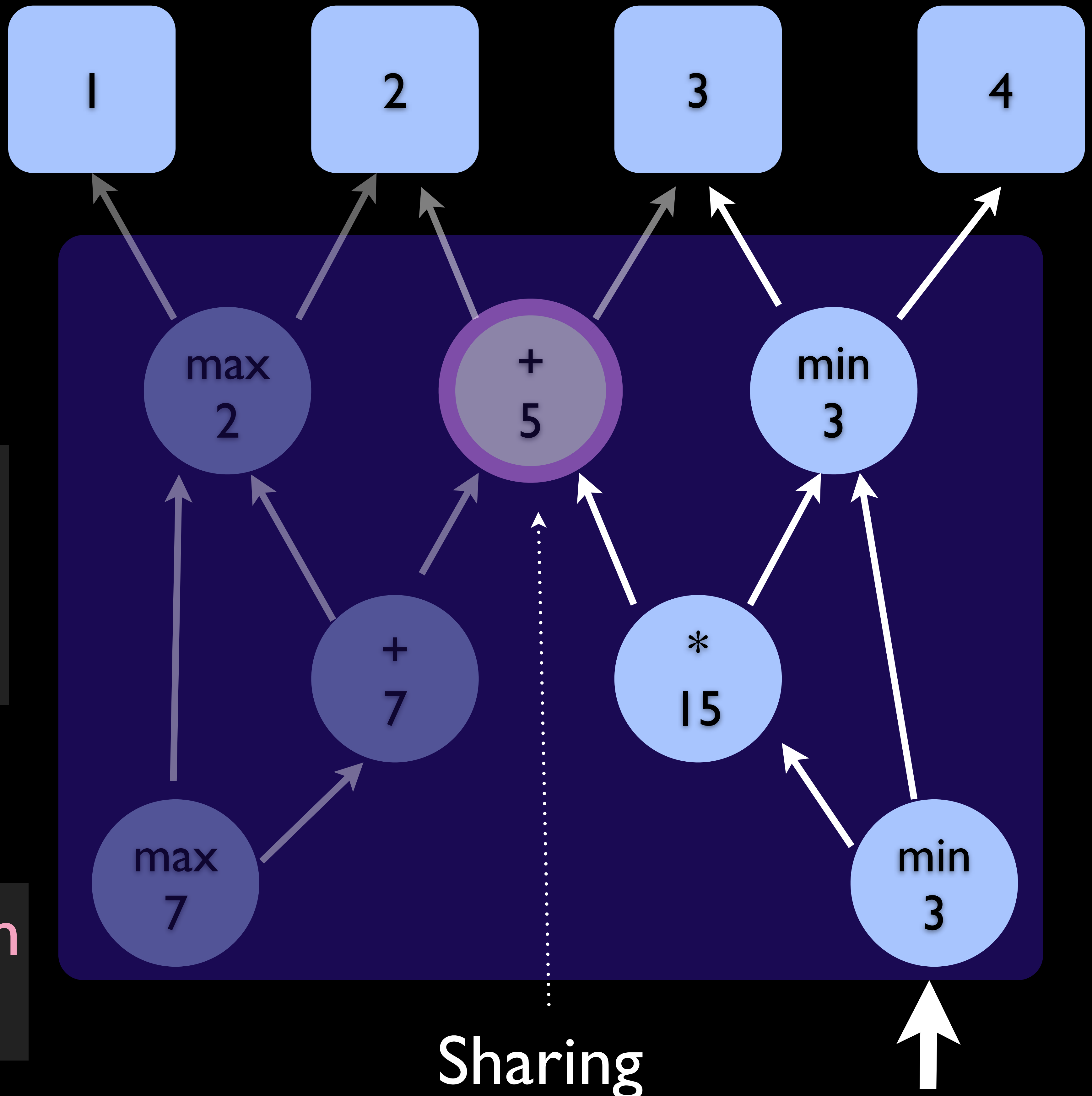


Switch Demand: ↑

Mutable references

Incremental Computation (thunks)

Demand-driven Outputs

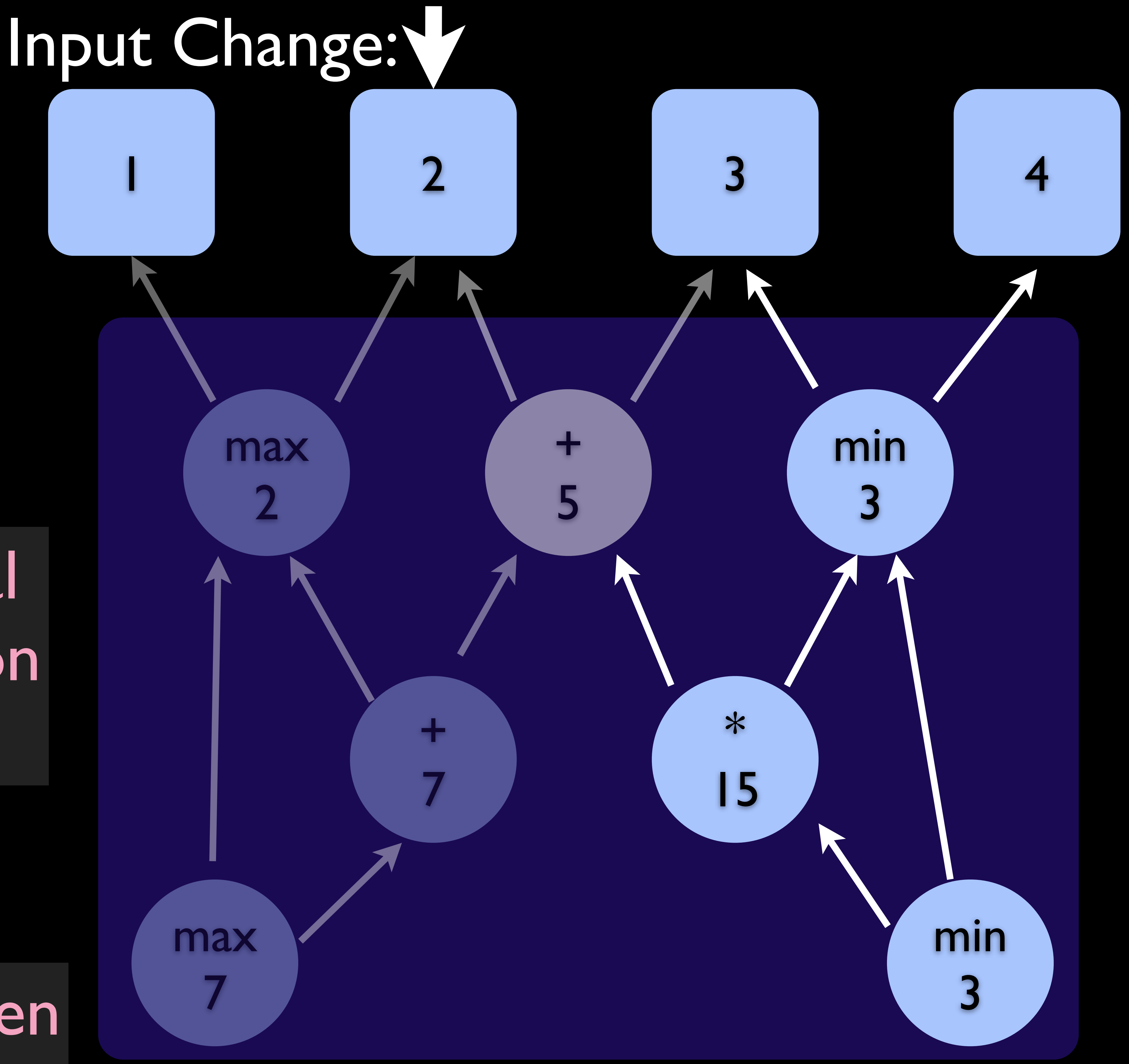


Sharing

Mutable references

Incremental Computation (thunks)

Demand-driven Outputs

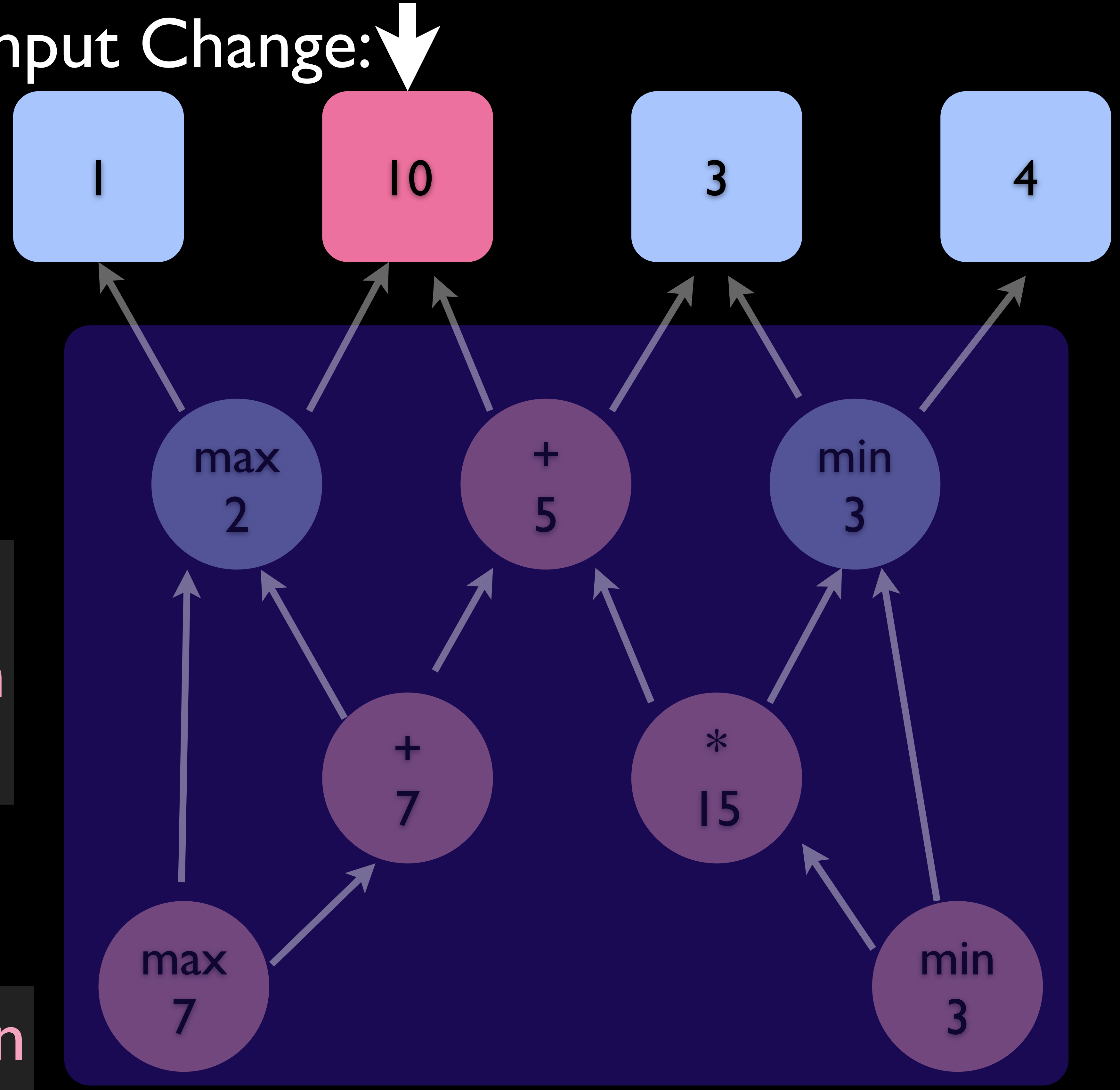


Input Change:

Mutable references

Incremental Computation (thunks)

Demand-driven Outputs

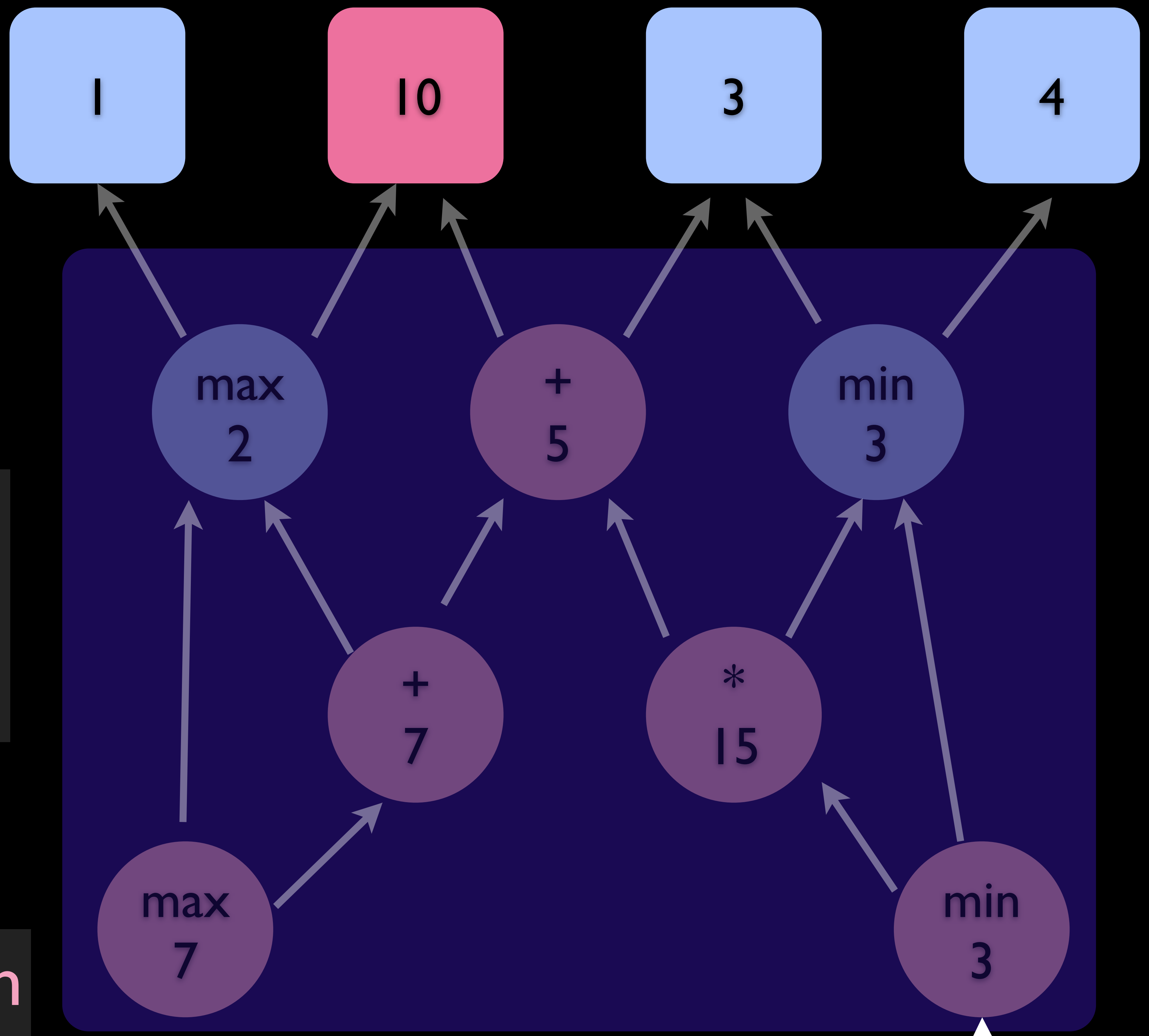


Some previous results are affected

Mutable references

Incremental Computation (thunks)

Demand-driven Outputs

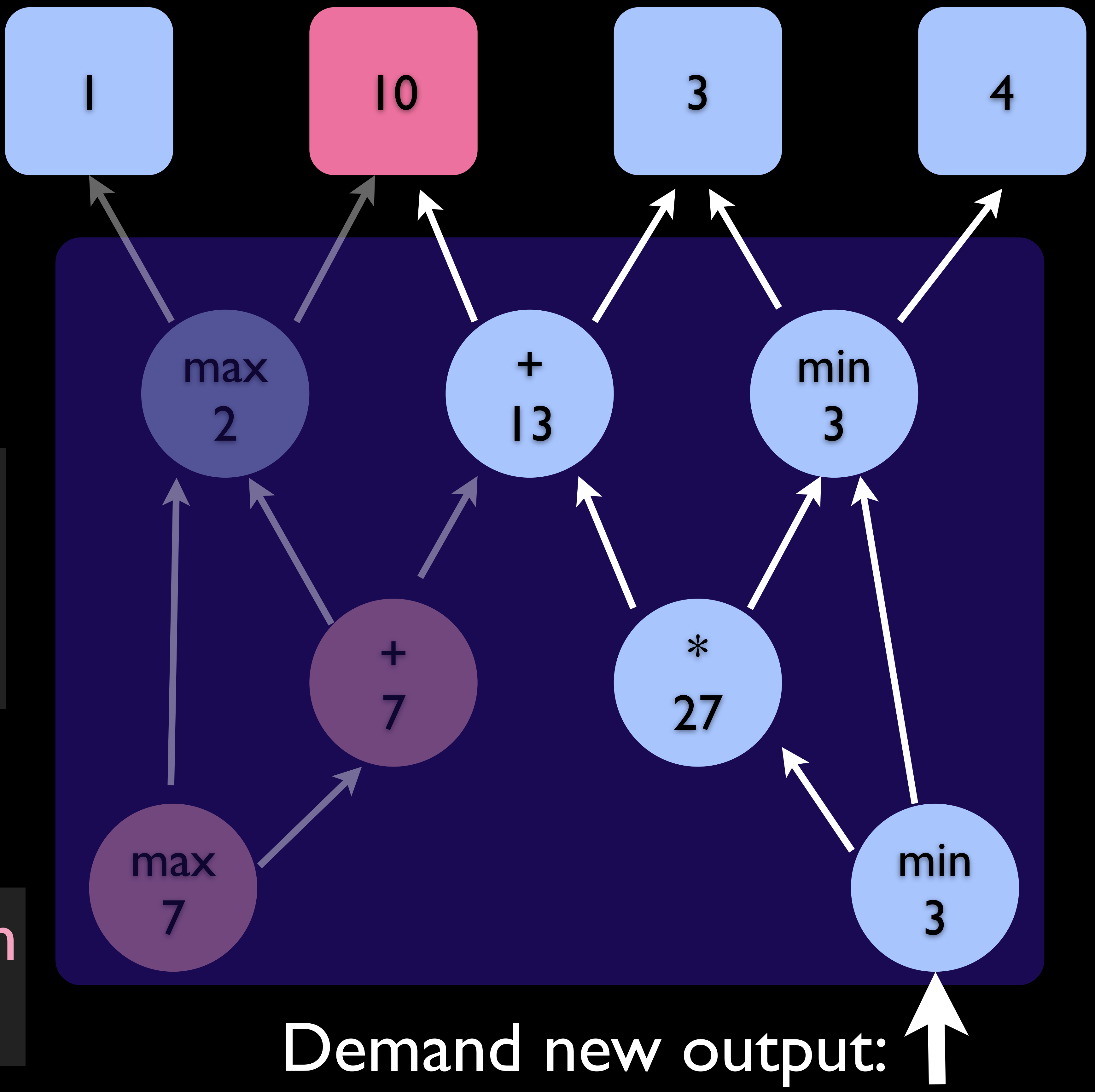


Demand new output: ↑

Mutable references

Incremental Computation (thunks)

Demand-driven Outputs



Demand new output:

Lazy Structures

- **Spreadsheet example:**
  - Each thunk returns a single number
- **Lazy Lists:**
  - Each thunk returns `Nil or `Cons
  - `Cons holds head value and a thunk tail
- Laziness can be applied to **trees**, **graphs**, and essentially any other data structure
- **Inputs**: Special thunks are **mutable**

Background: Lazy Lists

```
type 'a thunk = unit -> 'a

let force : 'a thunk -> 'a
  = fun t -> t ()

type 'a lzlist = [
  | `Nil
  | `Cons of 'a * ('a lzlist thunk)
  ]

let rec from_list l =
  match l with
    | []    -> `Nil
    | h::t -> `Cons(h,fun()->from_list t)
```

Apply unit argument

```
type 'a lzlist = [
  | `Nil
  | `Cons of 'a * ('a lzlist thunk)
  ]

let rec merge l1 l2 = function
  |l1,  `Nil -> l1
  |`Nil, l2 -> l2

  |`Cons(h1,t1), `Cons(h2,t2) ->

    if h1 <= h2 then
    `Cons(h1, fun()->merge (force t1) l2)

    else
    `Cons(h2, fun()->merge l1 (force t2))
```

Mergesort Example

Input	[3,5,8,2,1,7]
Singletons	[[3], [5], [8], [2], [1], [7]]
Merge #1	[[3,5], [2,8], [1,7]]
Merge #2	[[3,5], [1,2,7,8]]
Merge #3	[[3,5], [1,2,7,8]]
Merge #4	[[1, 2, 3, 5, 7, 8]]
Flatten	[1, 2, 3, 5, 7, 8]

Course Project

Project: Interactive Program Analysis

- Assume: Interactive “Structure Editor”
  - Programmer manipulates AST directly
- Learn: Adapton IC framework
- Build: Incremental Program Analysis
  - Example: Use/def information
  - Example: Type Inference
  - Example: Control-flow analysis

Background: Structure Editors

- Philosophical claims:
  - Programs consist of **rich structure**
  - Rich interaction **exposes this structure**

- Example prototypes:
  - **Haskell** -- http://www.youtube.com/watch?v=v2ypDcUM06U
  - **Citris** -- http://www.youtube.com/watch?v=47UcOspbZ2k
  - **TouchDevelop** -- http://www.youtube.com/watch?v=a6GRg2glKpc