Stack Implementations

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Today’s Plan

Announcements

Recap

Stack Implementations:

- Array
- Vector
- Linked Chain

Announcements and Syllabus Check

Queens College Hackathon

Stack ADT

```
#ifndef STACK_H_
#define STACK_H_

template<class ItemType>
class Stack
{

public:
    Stack();
    void push(const ItemType& newEntry); // adds an element to top of stack
    void pop(); // removes element from top of stack
    ItemType top() const; // returns a copy of element at top of stack
    int size() const; // returns the number of elements in the stack
    bool isEmpty() const; // returns true if no elements on stack false otherwise

private:
          //implementation details here


};    //end Stack

#include "Stack.cpp"
#endif // STACK_H_`
```

Choose a Data Structure

Array?

Vector?

Linked chain?

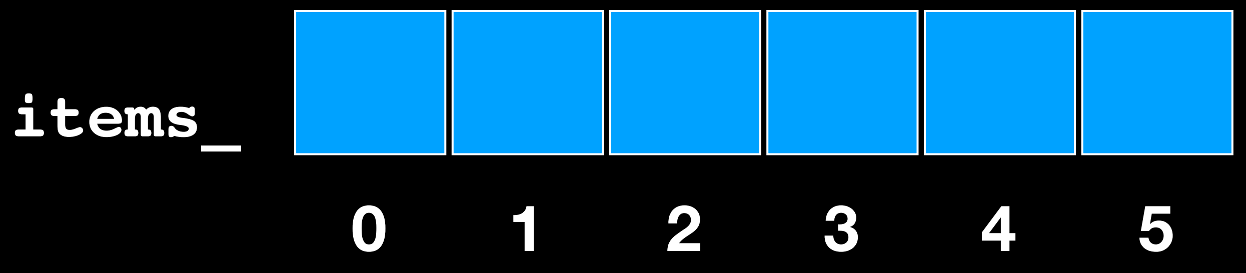
Choose a Data Structure

Inserting and removing from same end (**LIFO**)

Goal: minimize work (operations)

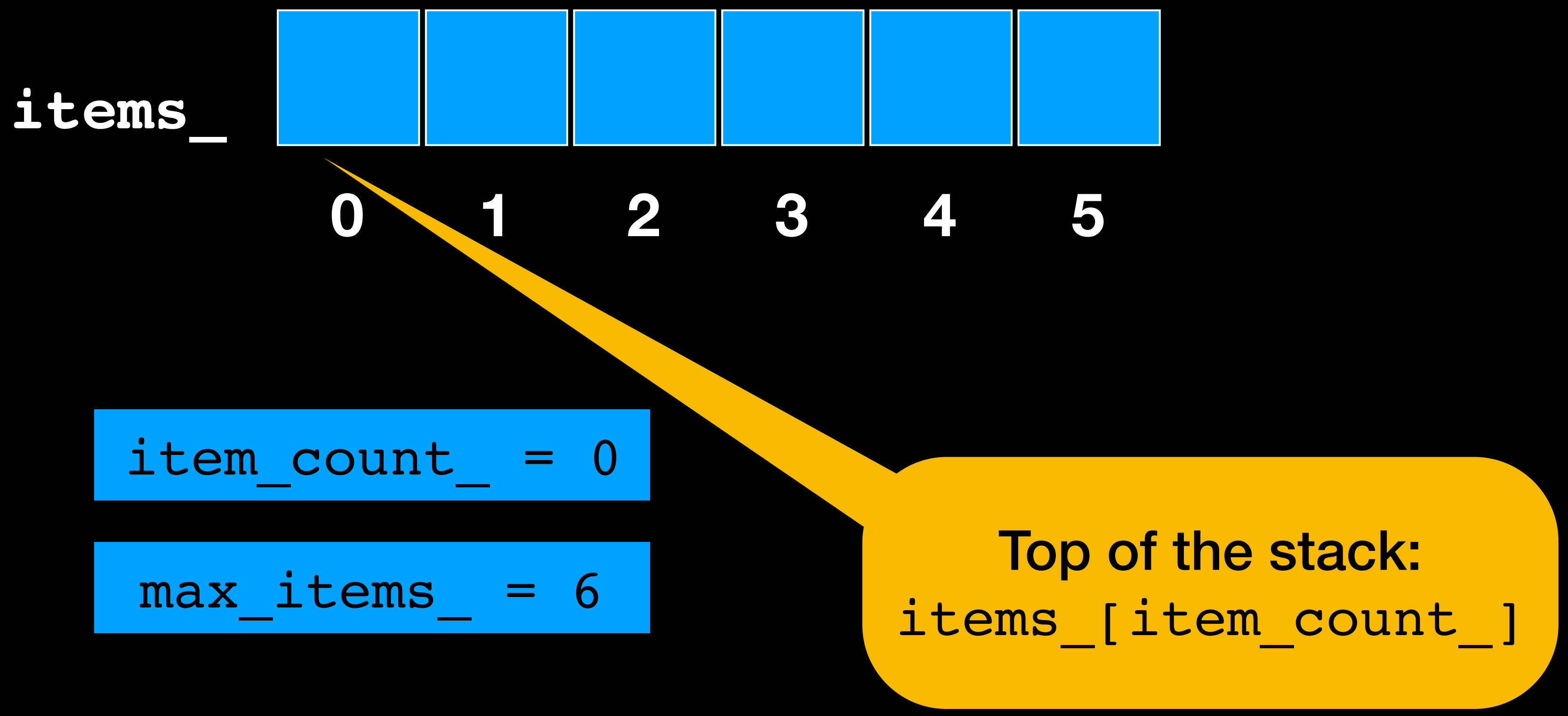
What would you suggest?

Array



Where is the top of the stack?

Array



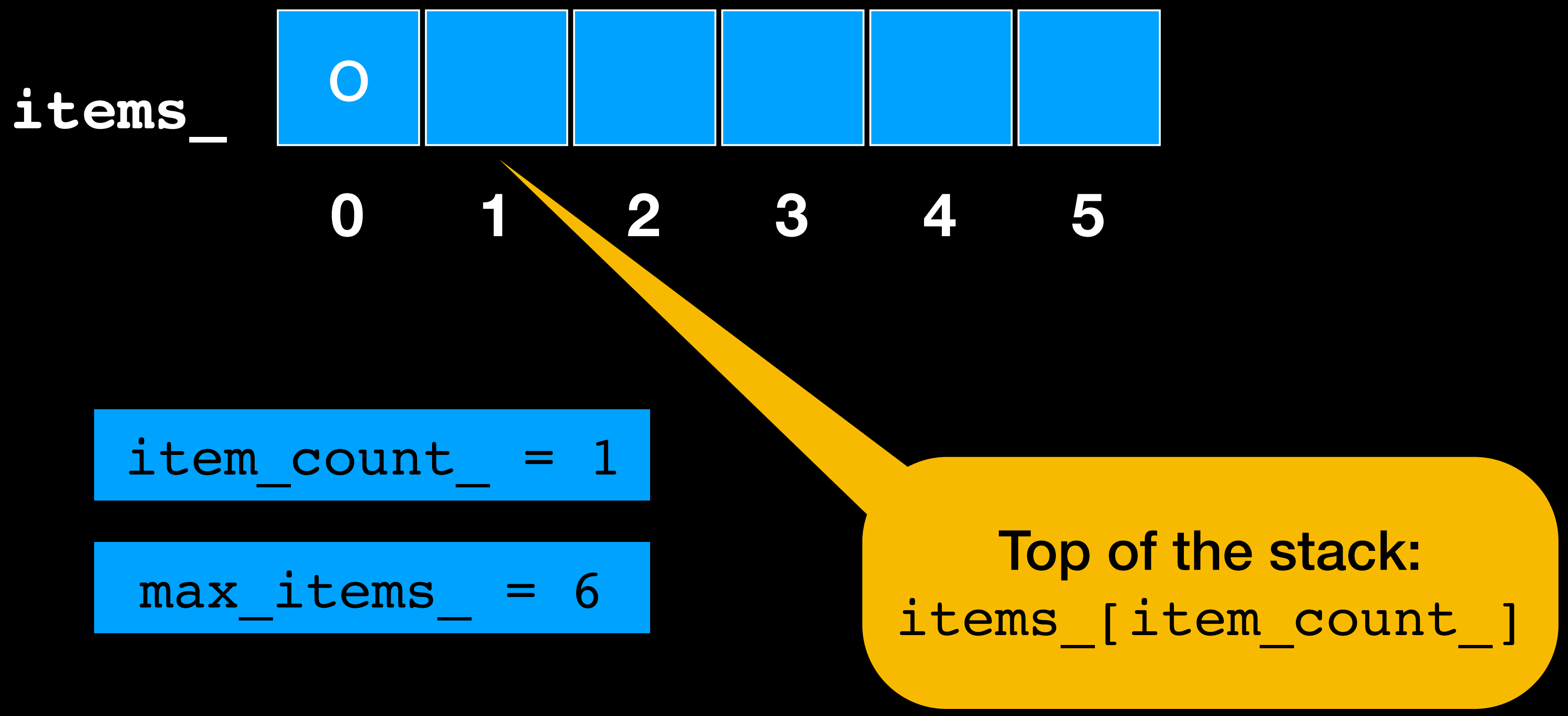
`item_count_ = 0`

`max_items_ = 6`

Top of the stack:
`items_[item_count_]`

Array

push('O')

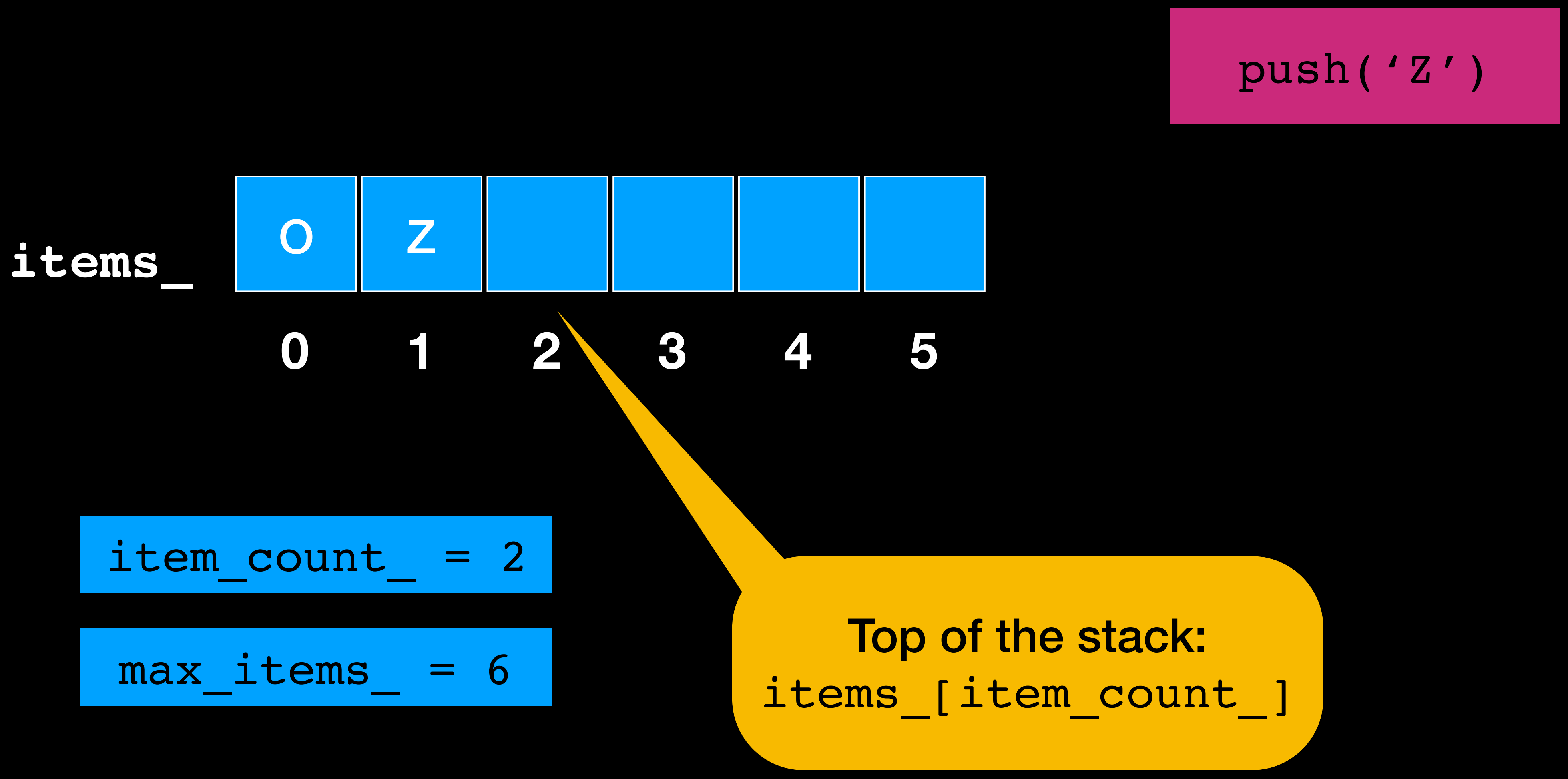


item_count_ = 1

max_items_ = 6

Top of the stack:
`items_[item_count_]`

Array



push(‘Z’)

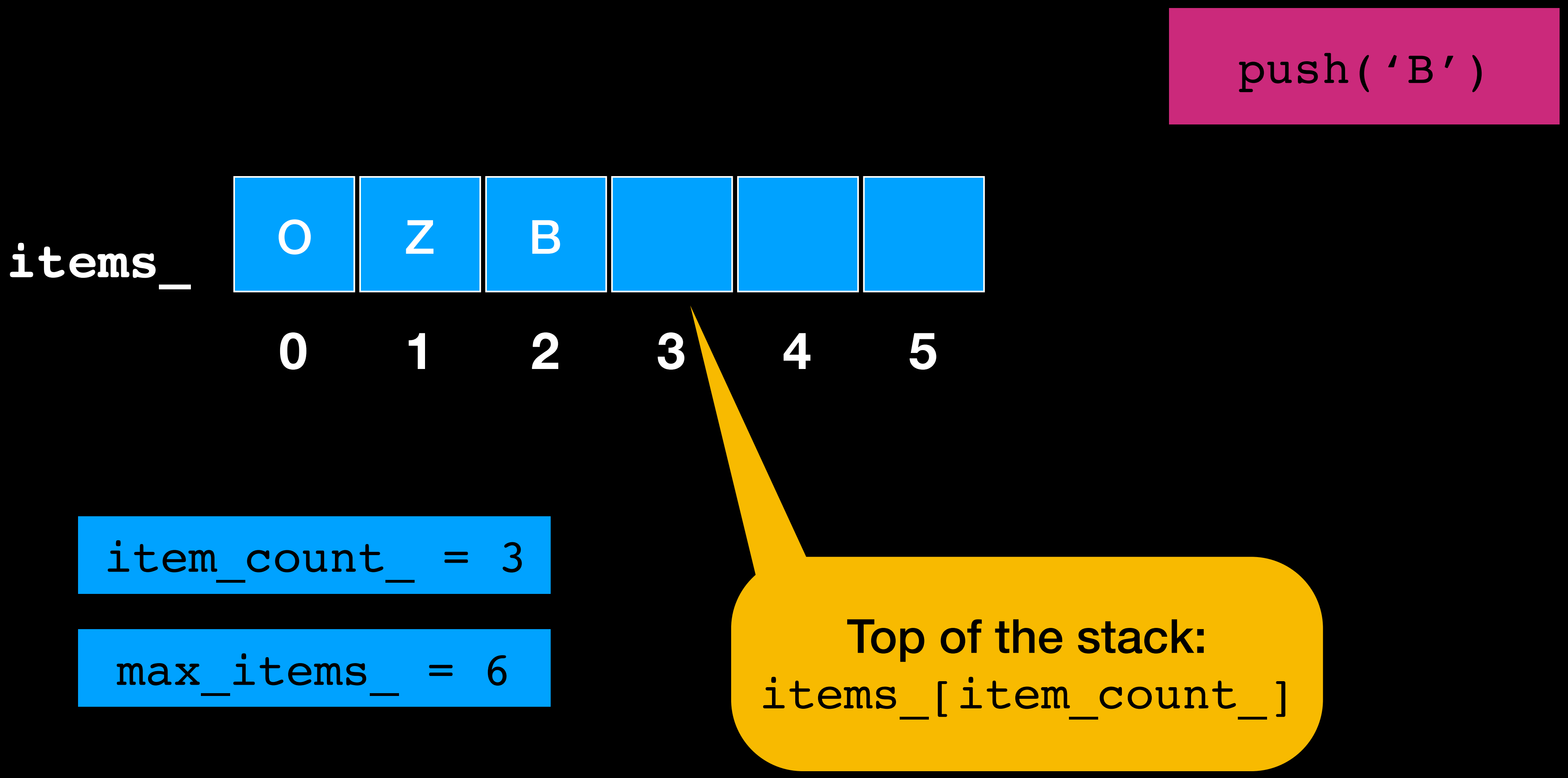
items_	O	Z				
	0	1	2	3	4	5

item_count_ = 2

max_items_ = 6

Top of the stack:
items_[item_count_]

Array



push('B')

items_

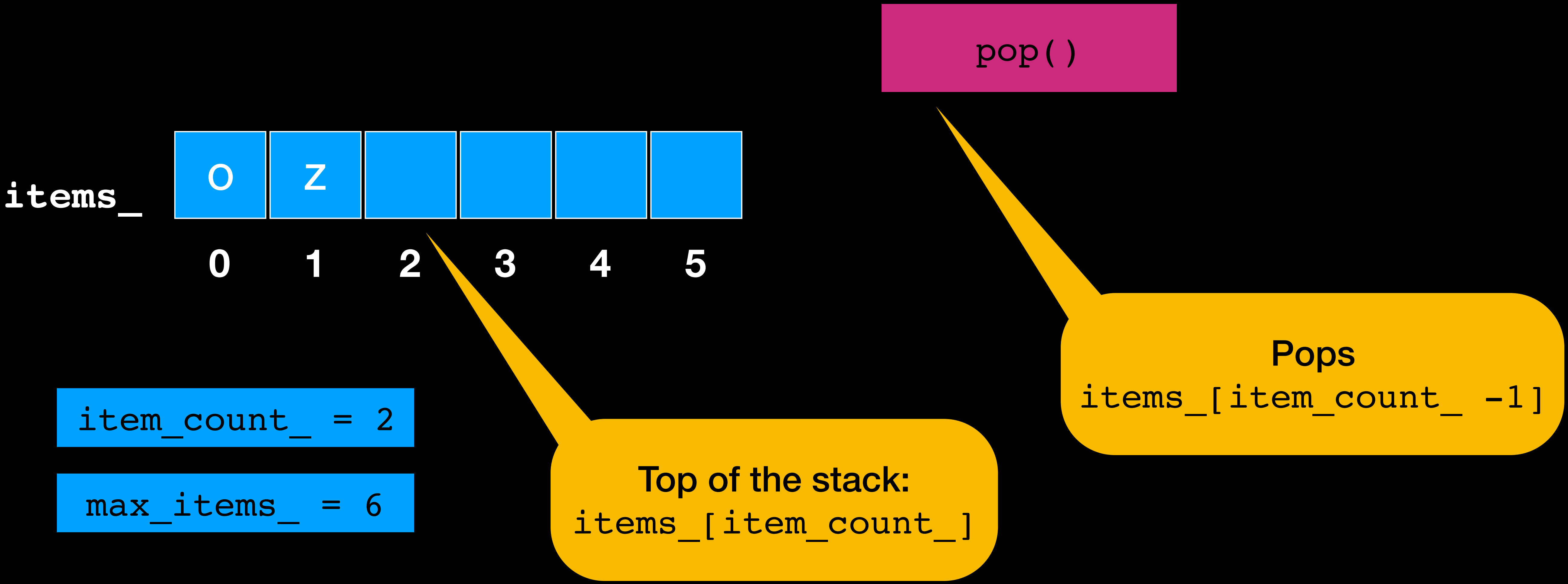
O	Z	B			
0	1	2	3	4	5

item_count_ = 3

max_items_ = 6

Top of the stack:
items_[item_count_]

Array



pop()

items_

O Z

0 1 2 3 4 5

`item_count_ = 2`

`max_items_ = 6`

Top of the stack:
`items_[item_count_]`

Pops
`items_[item_count_ -1]`

Array Analysis

1 assignment + 1 increment/decrement = 1 "*step*"

Fixed amount of work

`size` : 1 "*step*"

`isEmpty`: 1 "*step*"

`push`: 1 "*step*"

`pop` : 1 "*step*"

`top` : 1 "*step*"

GREAT!!!!

Array Analysis

1 assignment + 1 increment/decrement = 1 “*step*”

Fixed amount of work

`size` : 1 “*step*”

`isEmpty`: 1 “*step*”

`push`: 1 “*step*”

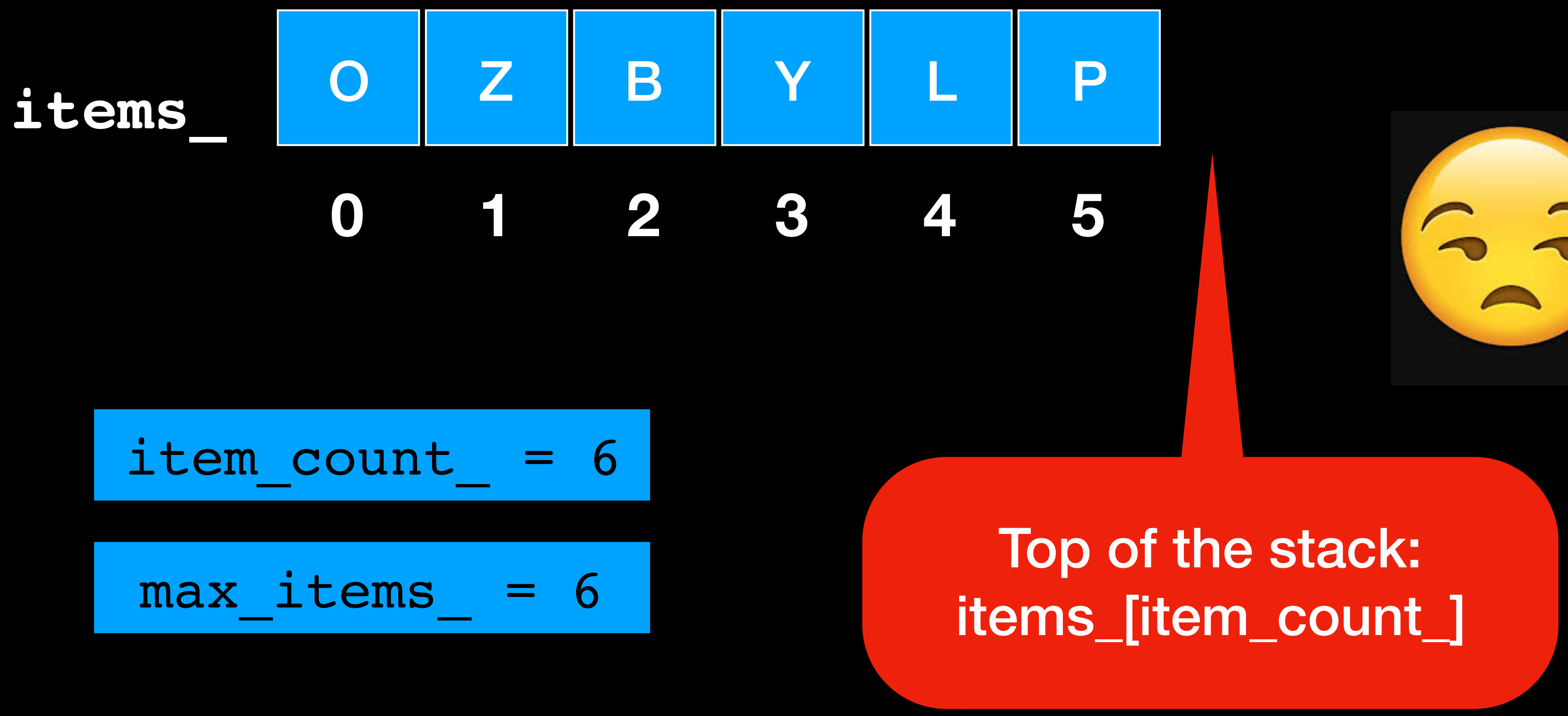
`pop` : 1 “*step*”

`top` : 1 “*step*”

GREAT???

Array

`push('T')`



items_	O	Z	B	Y	L	P
	0	1	2	3	4	5

`item_count_ = 6`

`max_items_ = 6`

Top of the stack:
items_[item_count_]

😒 Sorry Stack is Full!!!

Vector

```
std::vector<ItemType> some_vector;
```

So what is a vector really?

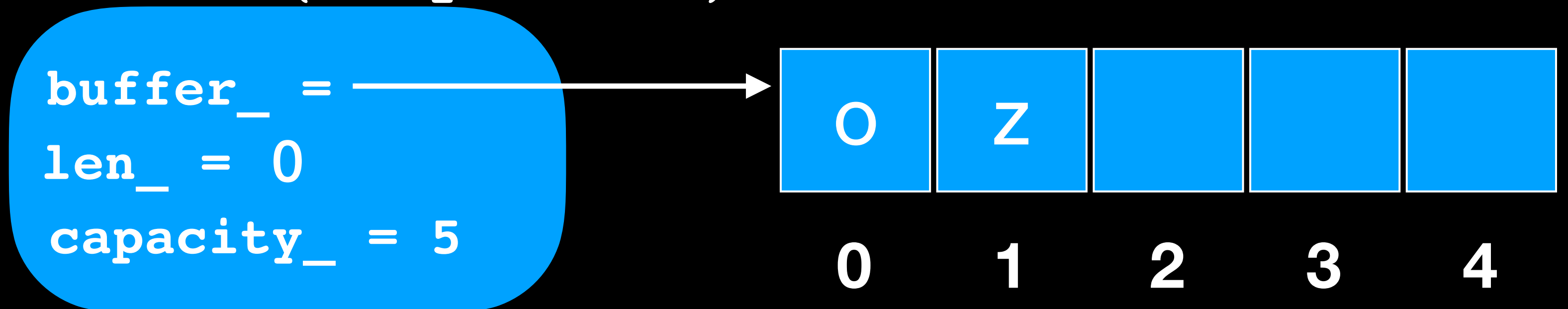
Vector

```
std::vector<ItemType> some_vector;
```

So what is a vector really?

Push and pop same as with arrays

Vector (simplified)

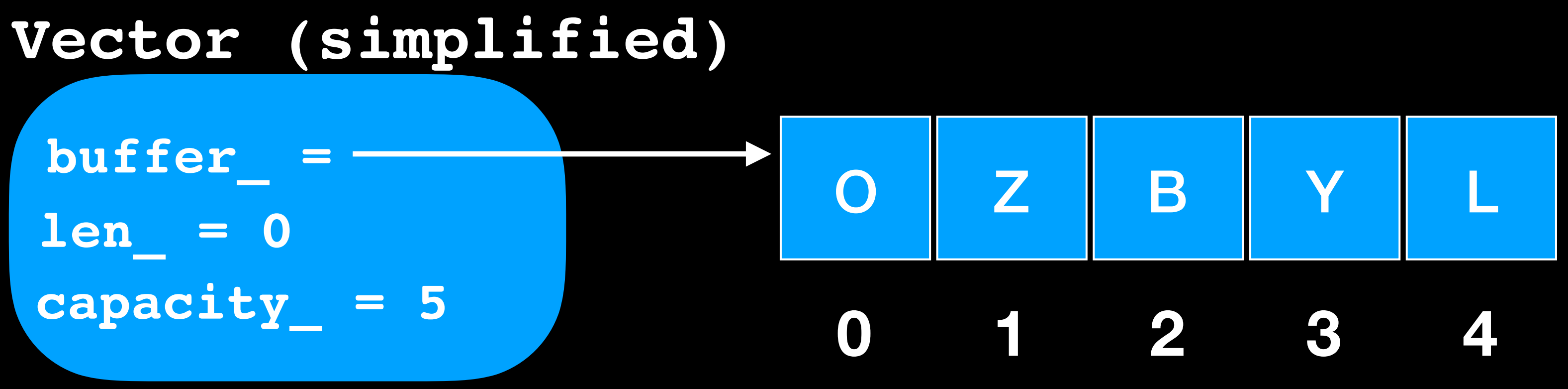


Vector

```
std::vector<ItemType> some_vector;
```

So what is a vector really?

Stack is Full?

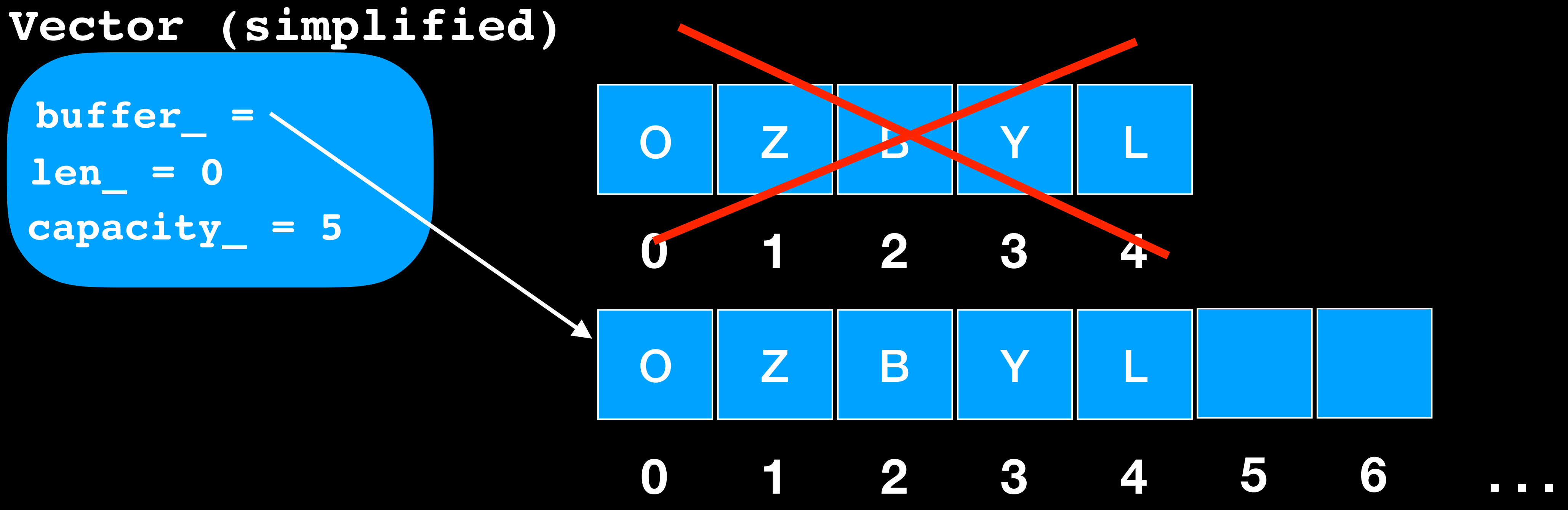


Vector

```
std::vector<ItemType> some_vector;
```

So what is a vector really?

No, I'll Grow!!!



Vector (simplified)

```
buffer_ =
len_ = 0
capacity_ = 5
```

~~O Z B Y L~~

~~0 1 2 3 4~~

O Z B Y L

0 1 2 3 4 5 6 ...

In-Class Task

How much should it grow?

Write a short paragraph arguing the pros and cons of growing by the amount you propose

Vector Analysis

1 assignment + 1 increment/decrement = 1 “*step*”

Fixed amount of work

`size` : 1 “*step*”

`isEmpty`: 1 “*step*”

`push`: 1 “*step*”

`pop` : 1 “*step*”

`top` : 1 “*step*”

GREAT!!!!

Vector Analysis

1 assignment + 1 increment/decrement = 1 "*step*"

Fixed amount of work

`size` : 1 "*step*"

`isEmpty`: 1 "*step*"

`push`: 1 "*step*"

`pop` : 1 "*step*"

`top` : 1 "*step*"

GREAT!!!! →

Except when stack is full must:

- allocate new array
- copy elements in new array
- delete old array

Vector Analysis

1 assignment + 1 increment/decrement = 1 *"step"*

Fixed amount of work

`size` : 1 *"step"*

`isEmpty`: 1 *"step"*

`push`: 1 *"step"* ***or sometimes*** *n "steps"*

`pop` : 1 *"step"*

`top` : 1 *"step"*

Except when stack is full must:

- allocate new array (*assume 1 step*)
- copy elements in new array (***n steps***)
- delete old array (*assume 1 step*)

GREAT!!!! →

How should Vector grow?

Sometimes 1 *“step”*

Sometimes n *“steps”*

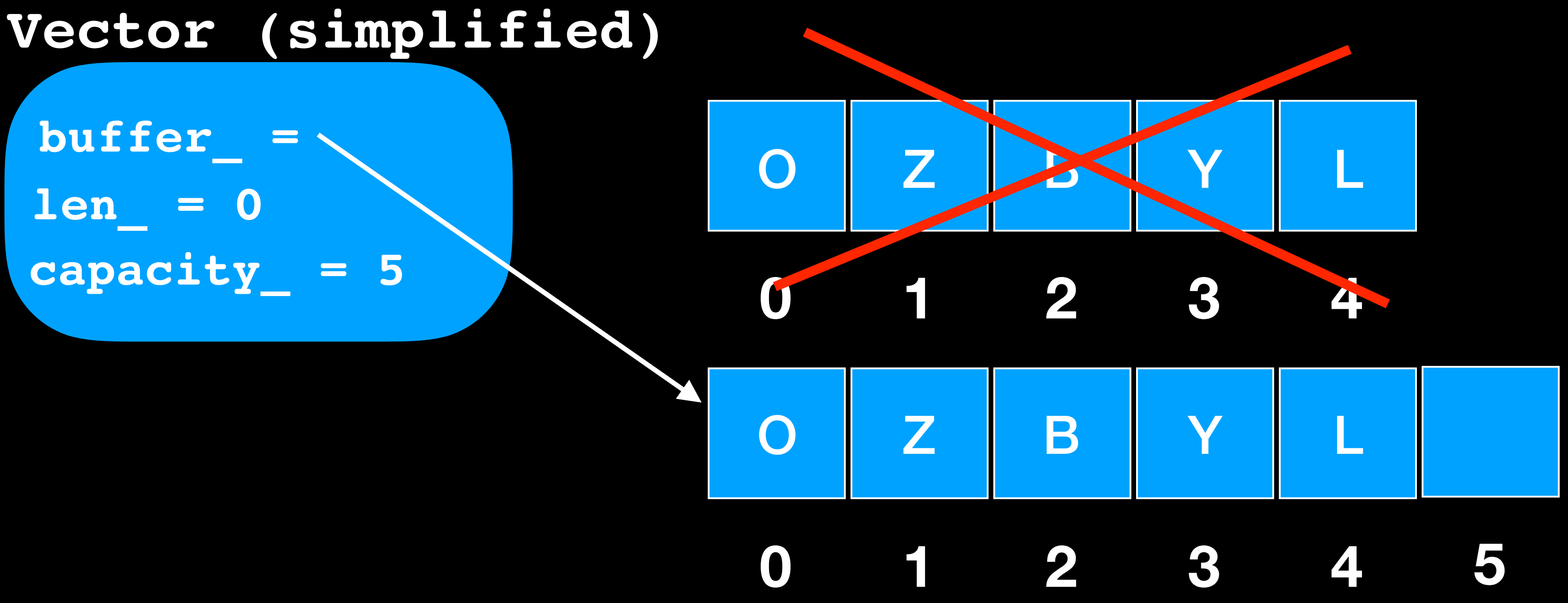
Consider behavior over several pushes (**on average**)

Vector Growth: a naive approach

```
std::vector<ItemType> some_vector;
```

So what is a vector really?

I'll Grow!!!
I will add space for the item to be added



Vector (simplified)

```
buffer_ =
len_ = 0
capacity_ = 5
```

~~O~~	~~Z~~	~~B~~	~~Y~~	~~L~~
0	1	2	3	4

O	Z	B	Y	L	
0	1	2	3	4	5

Vector Growth: a naive approach

If vector grows by 1 each time, every push costs n "*steps*"

Cost of pushes:

$1 + 2 + 3 + 4 + 5 + . . . + n$

$= n\,(n+1)/2$

Vector Growth: a naive approach

If vector grows by 1 each time, every push costs n "*steps*"

Cost of pushes:

$1 + 2 + 3 + 4 + 5 + . . . + n$

$= n (n+1)/2$

$= n^2 /2 + n / 2$

$= n^2$ / something + something / something

n^2 highest degree

Vector Growth: a naive approach

If vector grows by 1 each time, every push costs n “*steps*”

Cost of pushes:

$1 + 2 + 3 + 4 + 5 + . . . + n$

$= n\,(n+1)/2$

$= n^2 + n \,/\, 2$

$= n^2 +$ something / something

n^2 highest degree

Same cost of pop:

$1 + 1 + 1 + . . . + 1$

$= n$

$= n +$ nothing / nothing

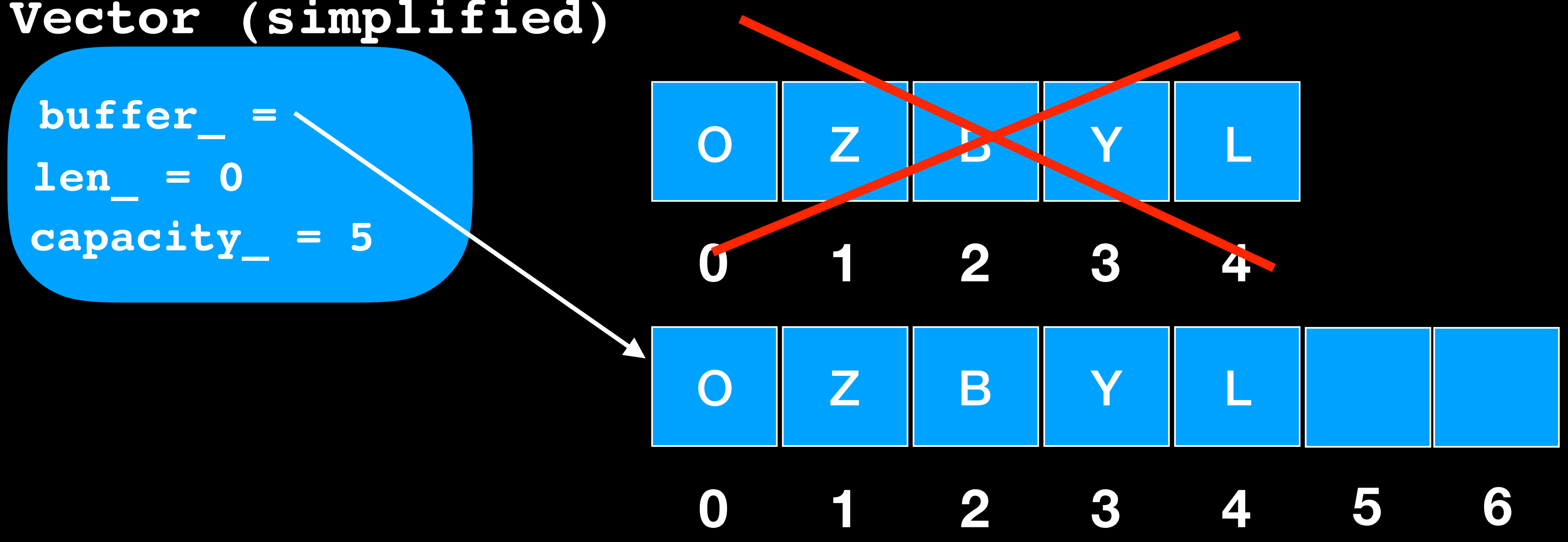
n highest degree

Vector Growth: a better approach

```
std::vector<ItemType> some_vector;
```

So what is a vector really?

I'll Grow!!!
I will add two more slots!



Vector (simplified)

```
buffer_ =
len_ = 0
capacity_ = 5
```

Vector Growth: a better approach

Let a “hard push” be one where the whole vector needs to be copied

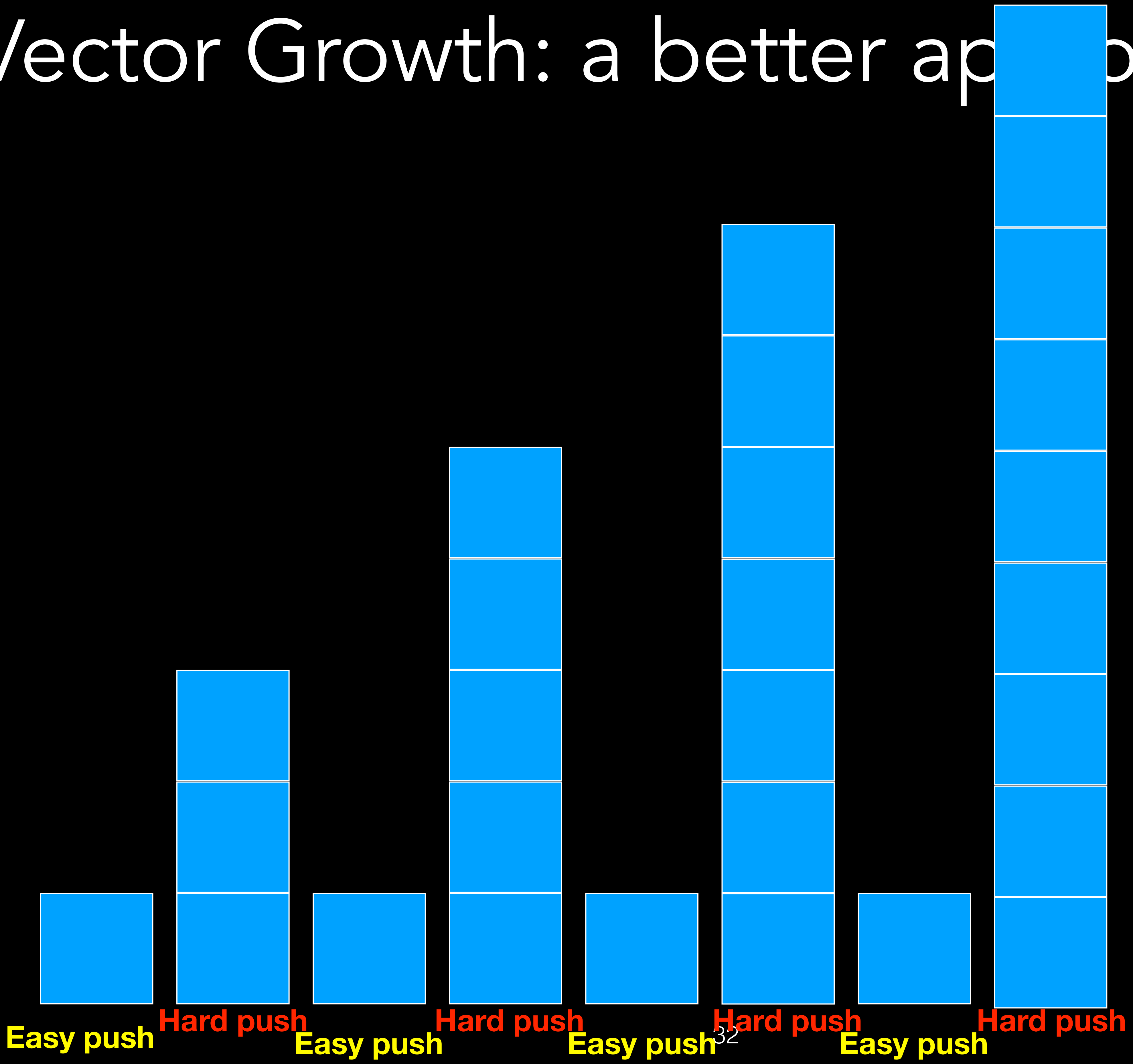
When vector is not copied we have an “easy push”

Now half our pushes will be easy (1 step) and half will be hard (n steps)

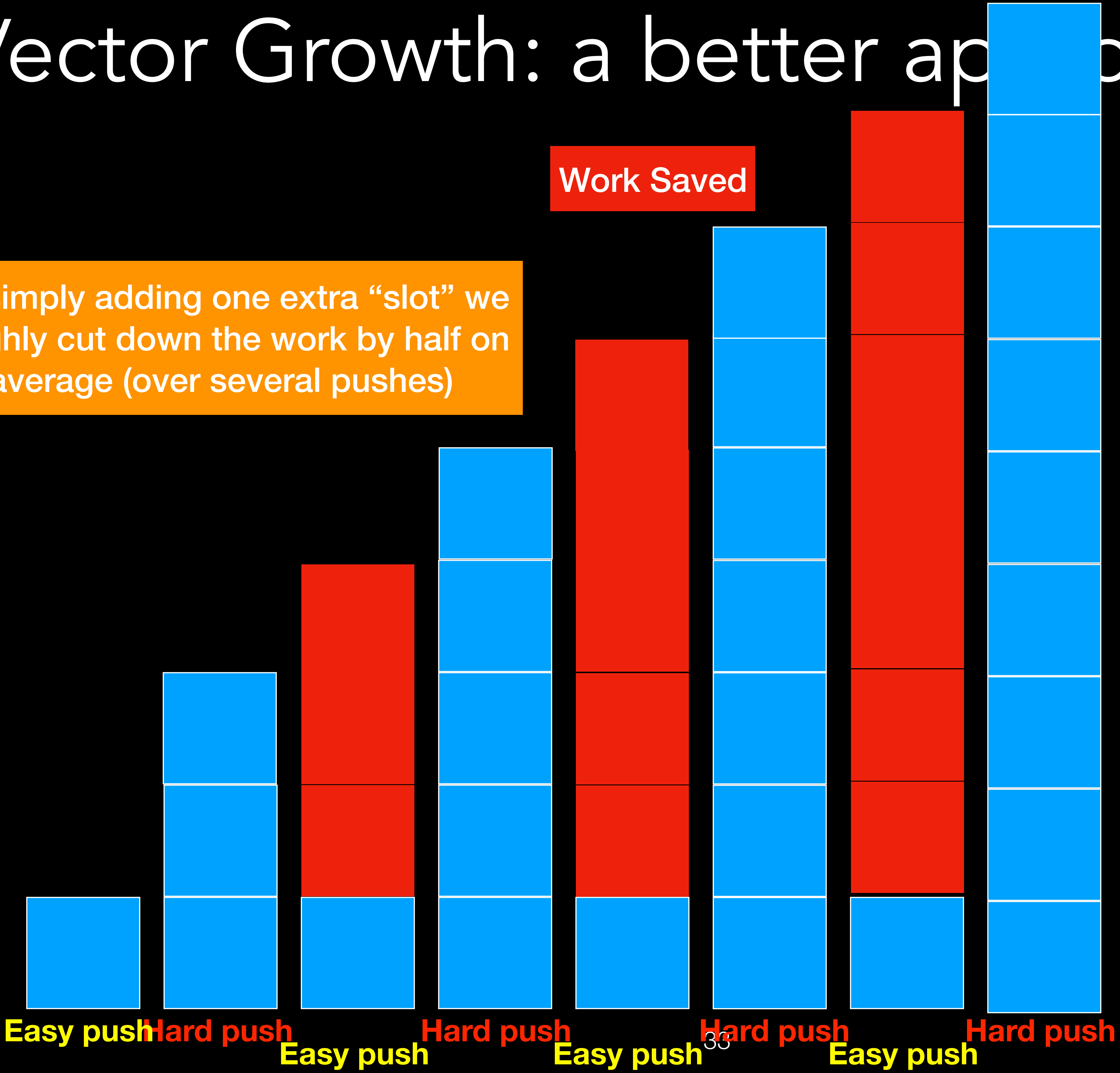
So if reconsider the work over several pushes? (On Average?)

Analysis visualization adapted from Keith Schwarz

Vector Growth: a better approach



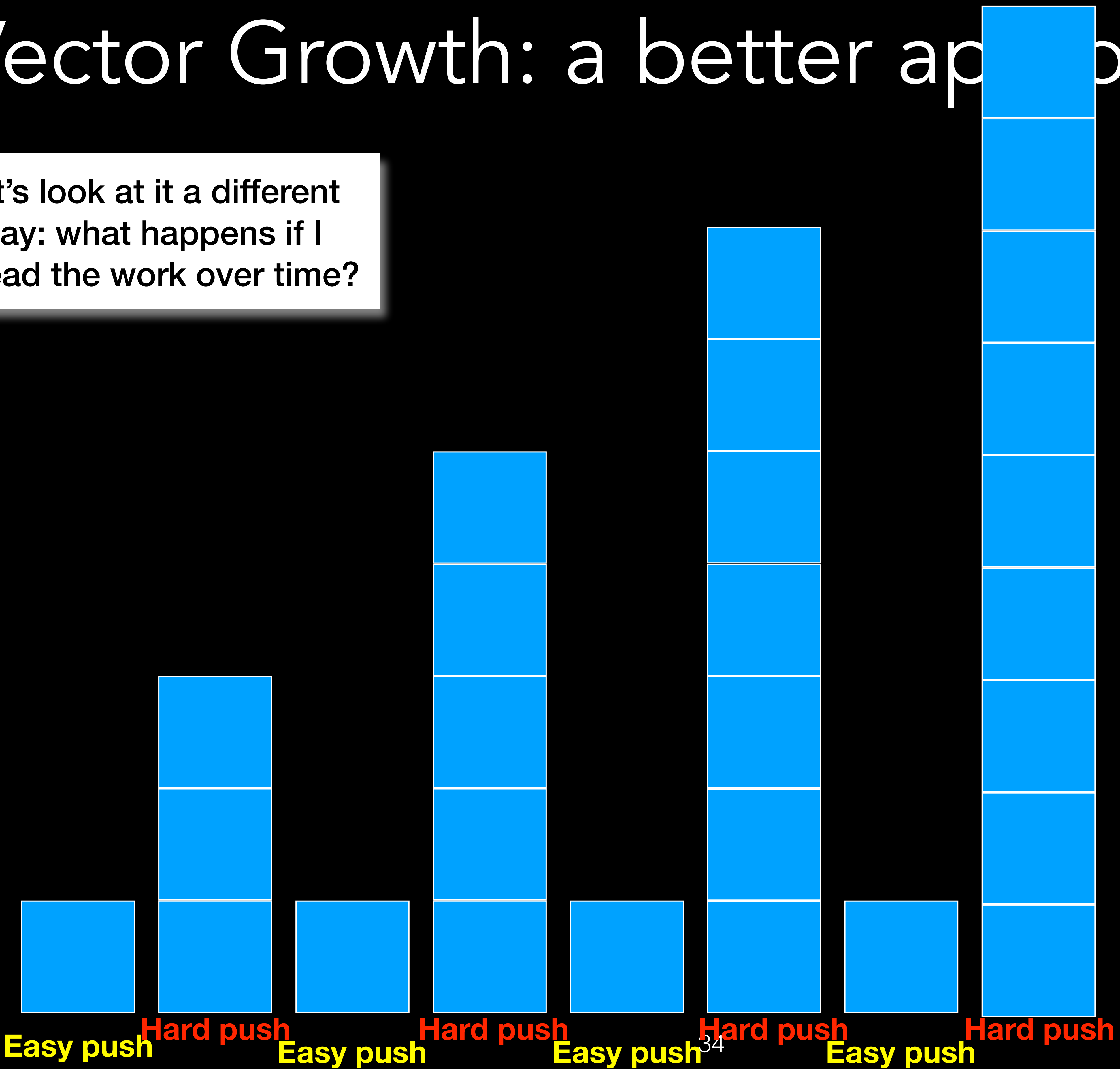
Vector Growth: a better ap   oach



By simply adding one extra “slot” we roughly cut down the work by half on average (over several pushes)

Vector Growth: a better ap bach

Let's look at it a different way: what happens if I spread the work over time?



Vector Growth: a better approach

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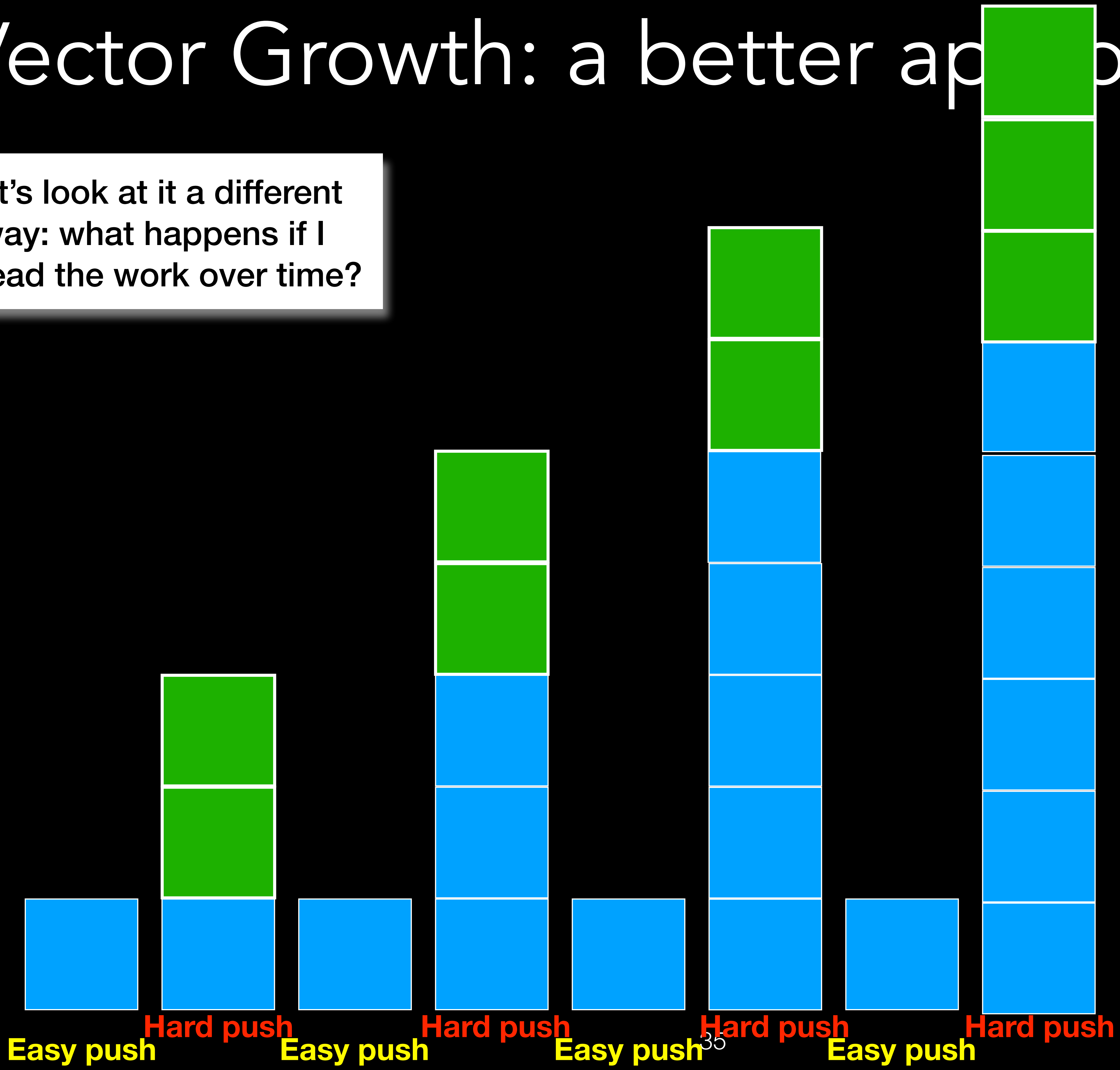
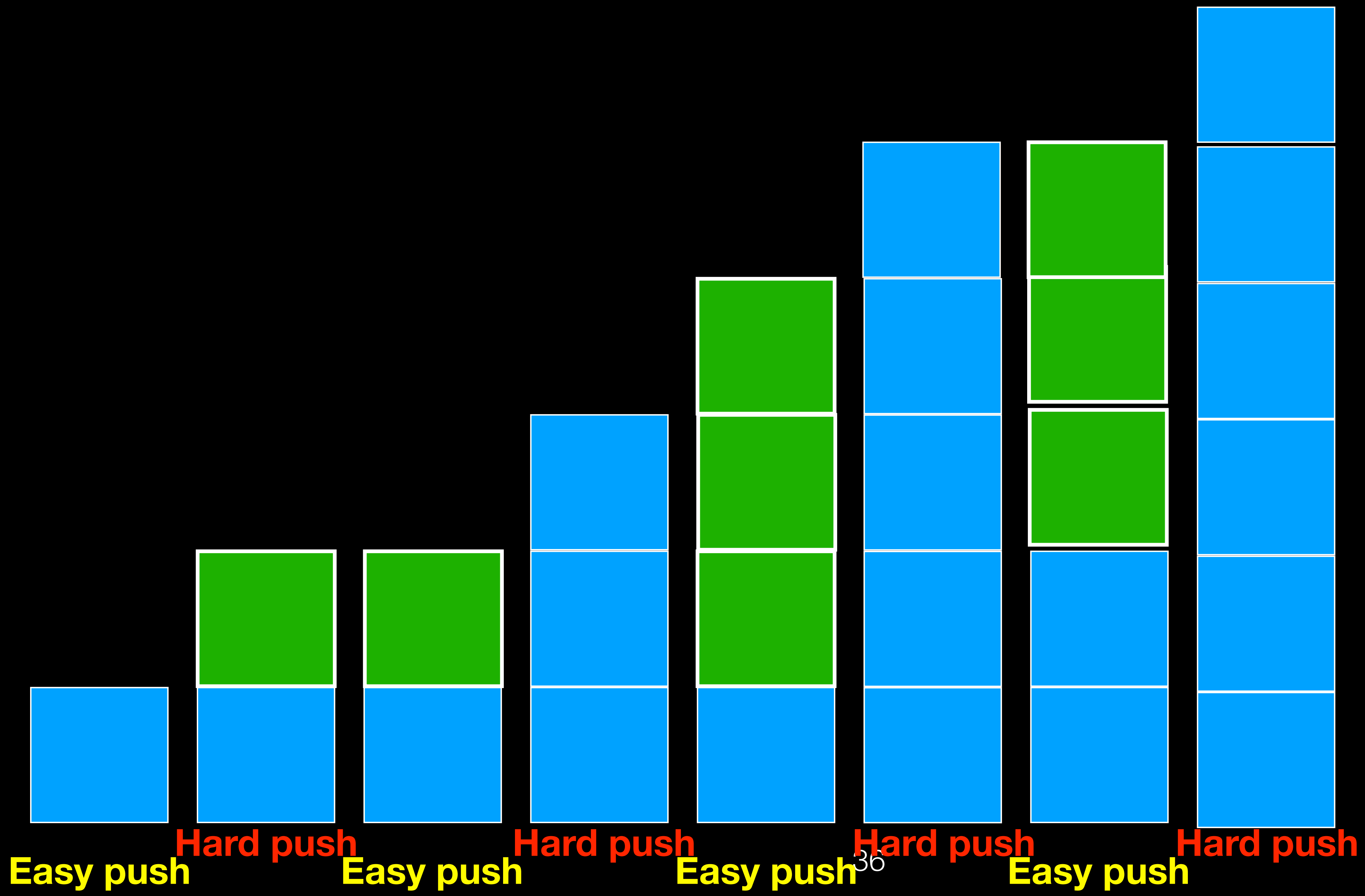


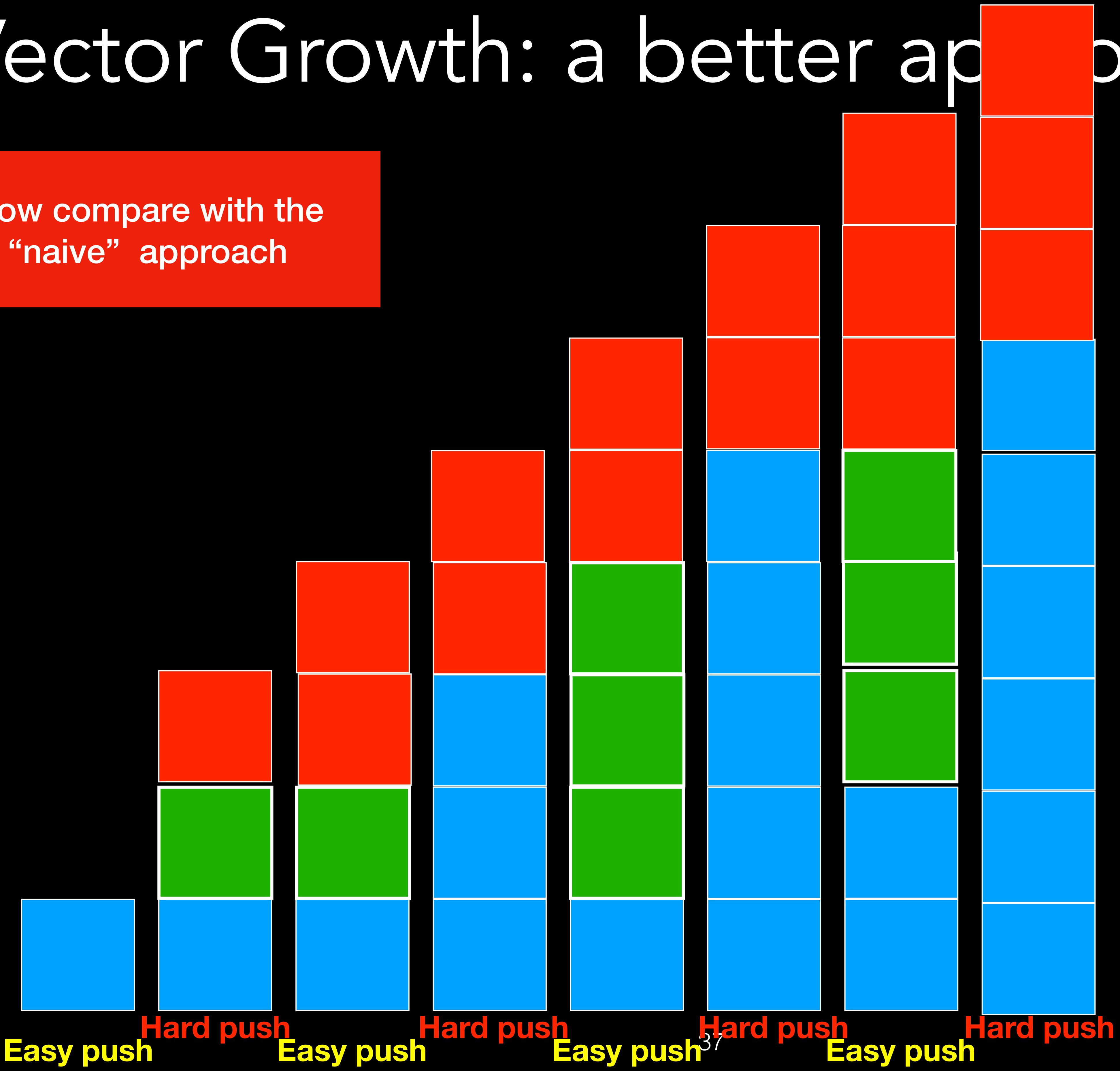
Vector Growth: a better approach

Let's look at it a different way: what happens if I spread the work over time?



Vector Growth: a better approach

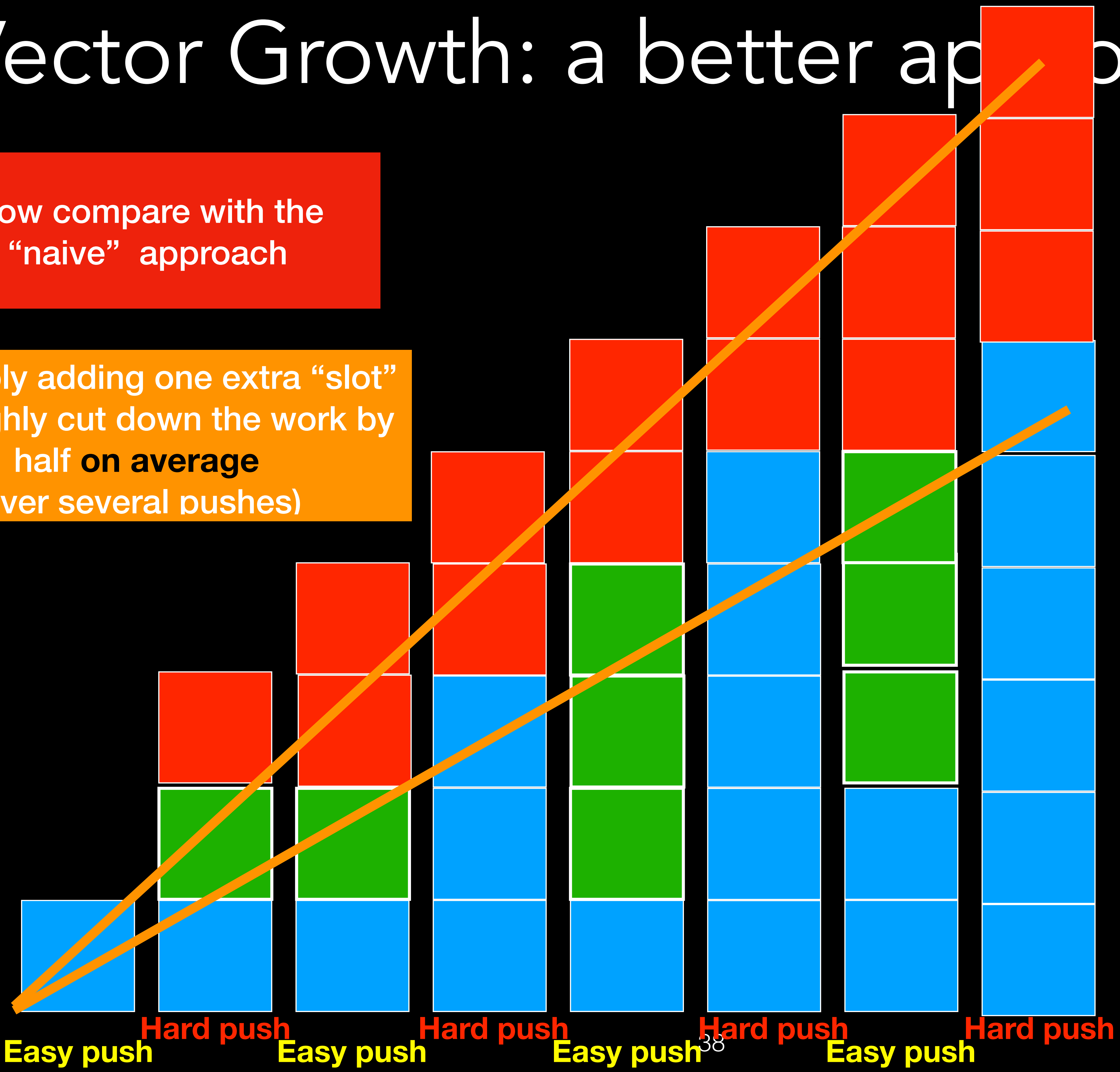
Now compare with the "naive" approach



Vector Growth: a better approach

Now compare with the “naive” approach

By simply adding one extra “slot” we roughly cut down the work by half on average
(over several pushes)



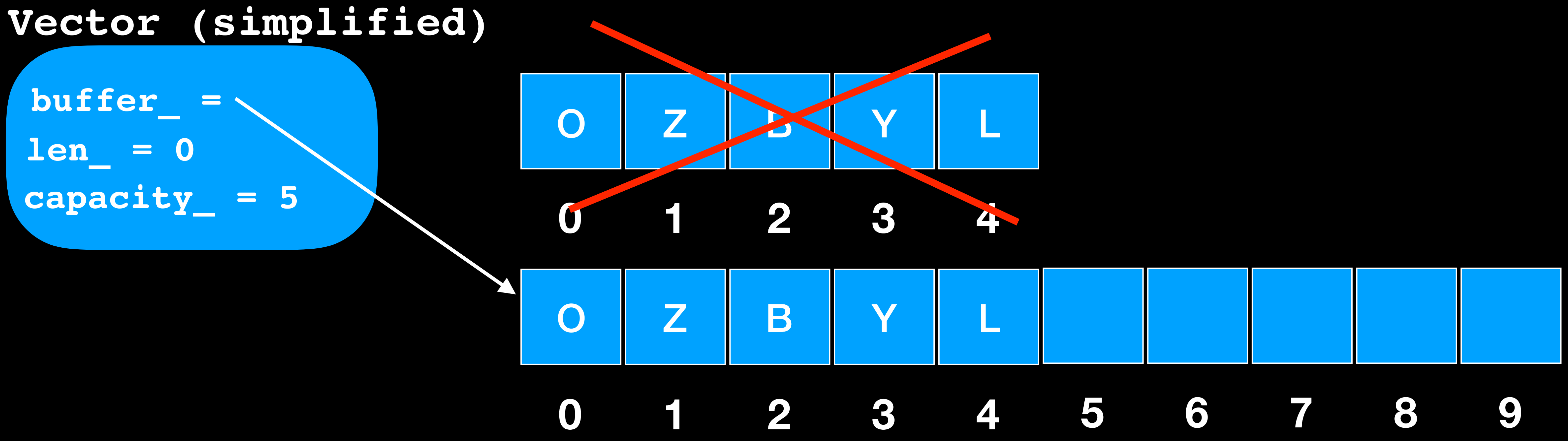
Can we do better?

Vector Growth: a much better approach

```
std::vector<ItemType> some_vector;
```

So what is a vector really?

I’ll Grow!!!
I’ll double my size!



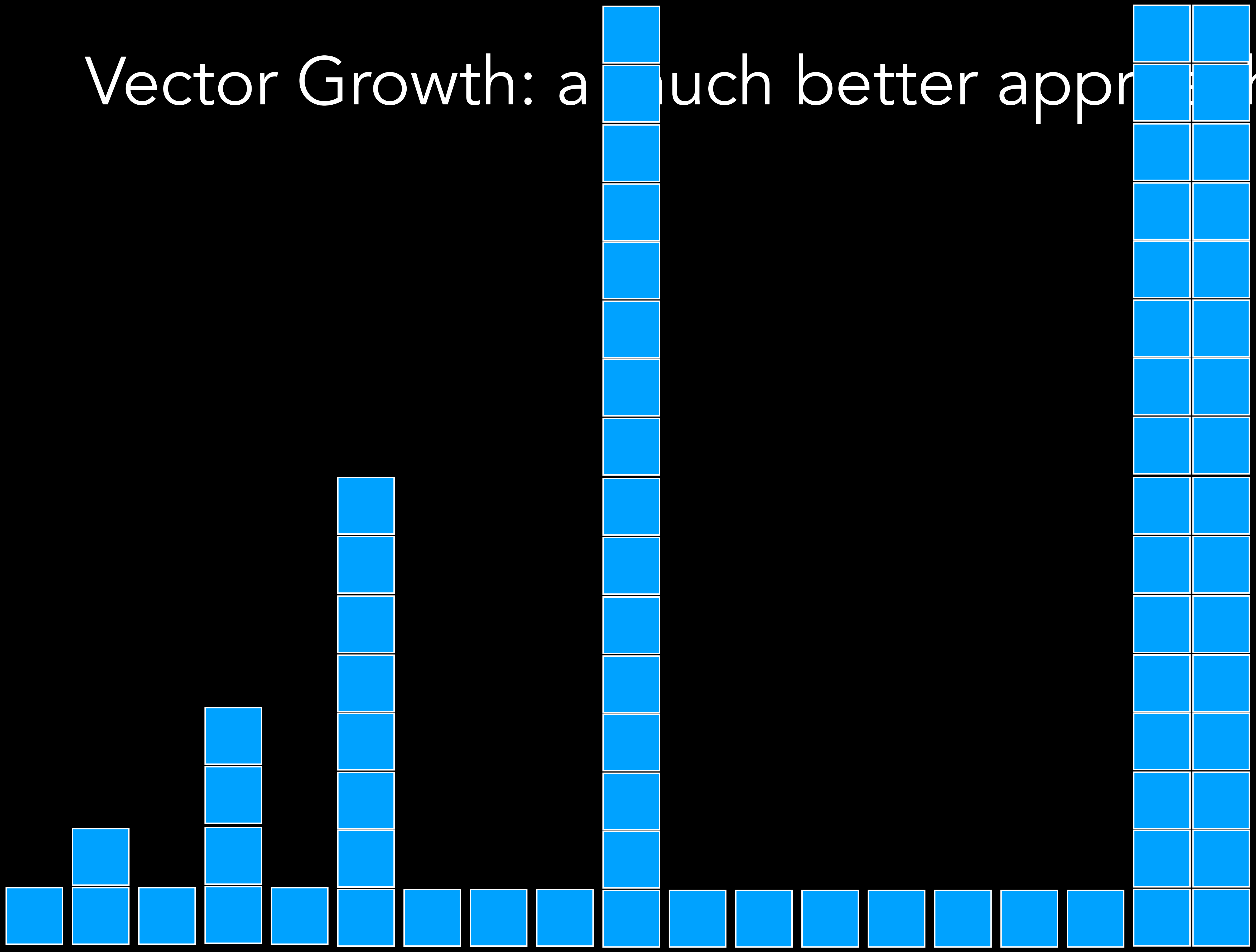
Vector (simplified)

```
buffer_ =
len_ = 0
capacity_ = 5
```

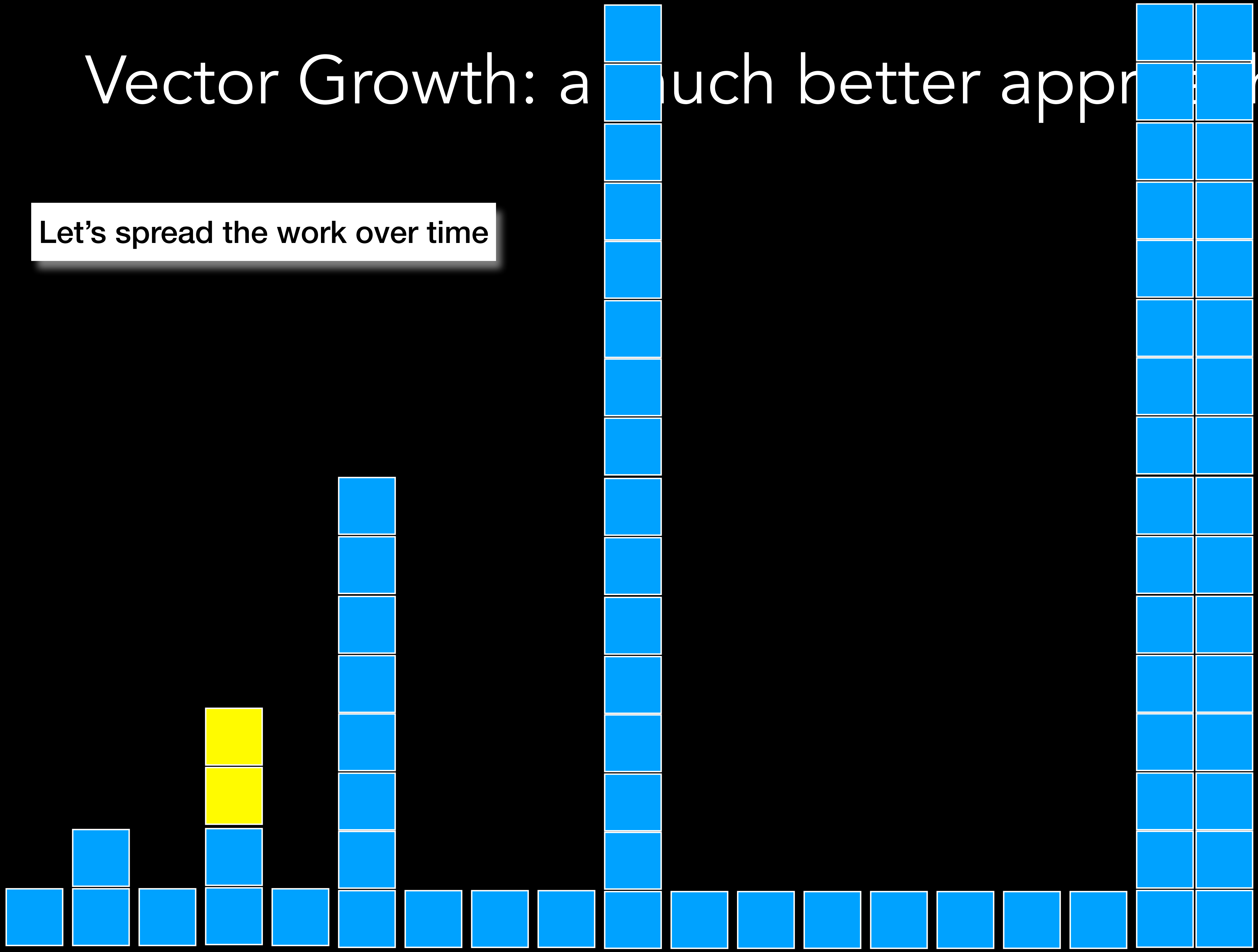
0	1	2	3	4
~~O~~	~~Z~~	~~B~~	~~Y~~	~~L~~

0	1	2	3	4	5	6	7	8	9
O	Z	B	Y	L					

Vector Growth: a much better approach

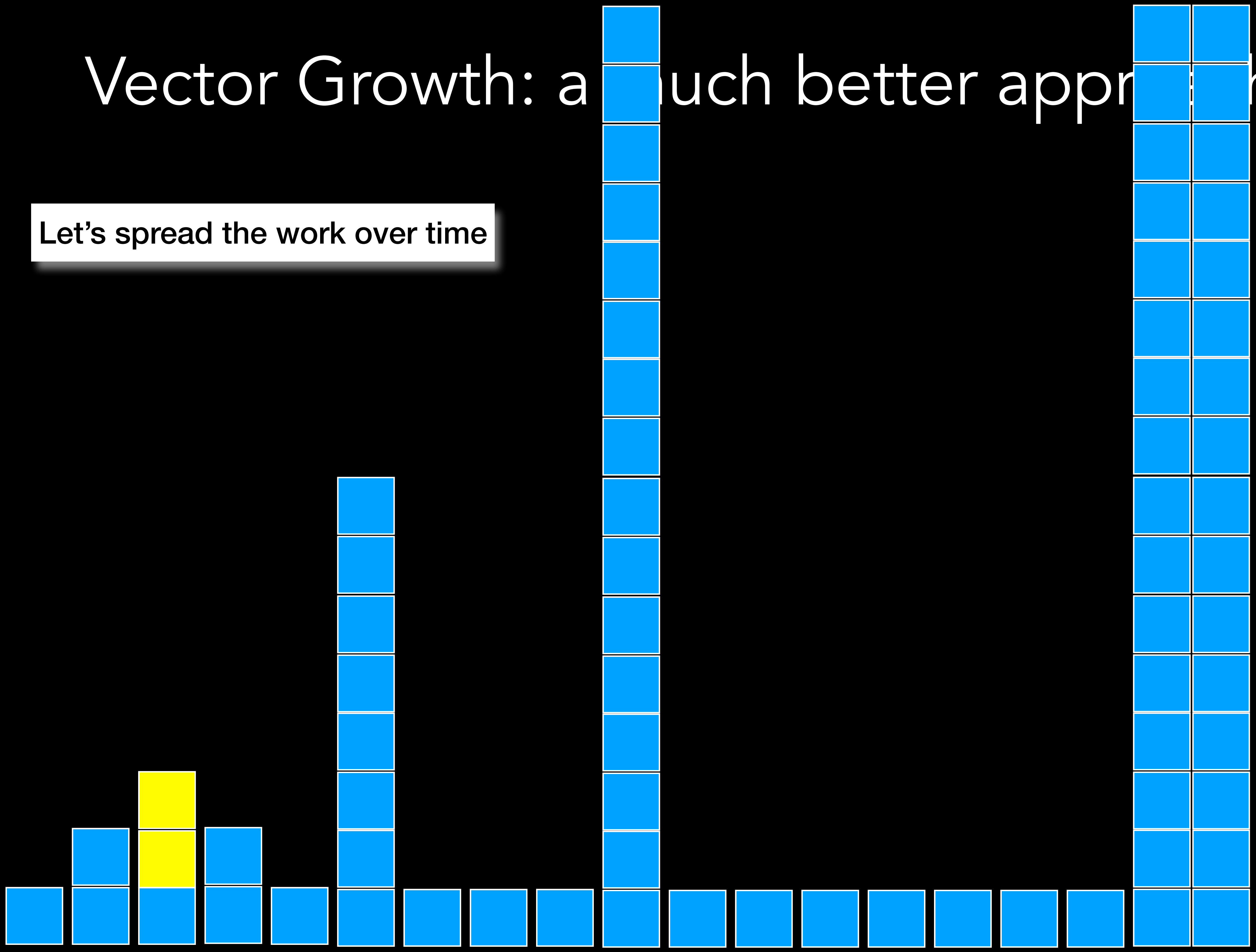


Vector Growth: a much better approach



Let's spread the work over time

Vector Growth: a much better approach



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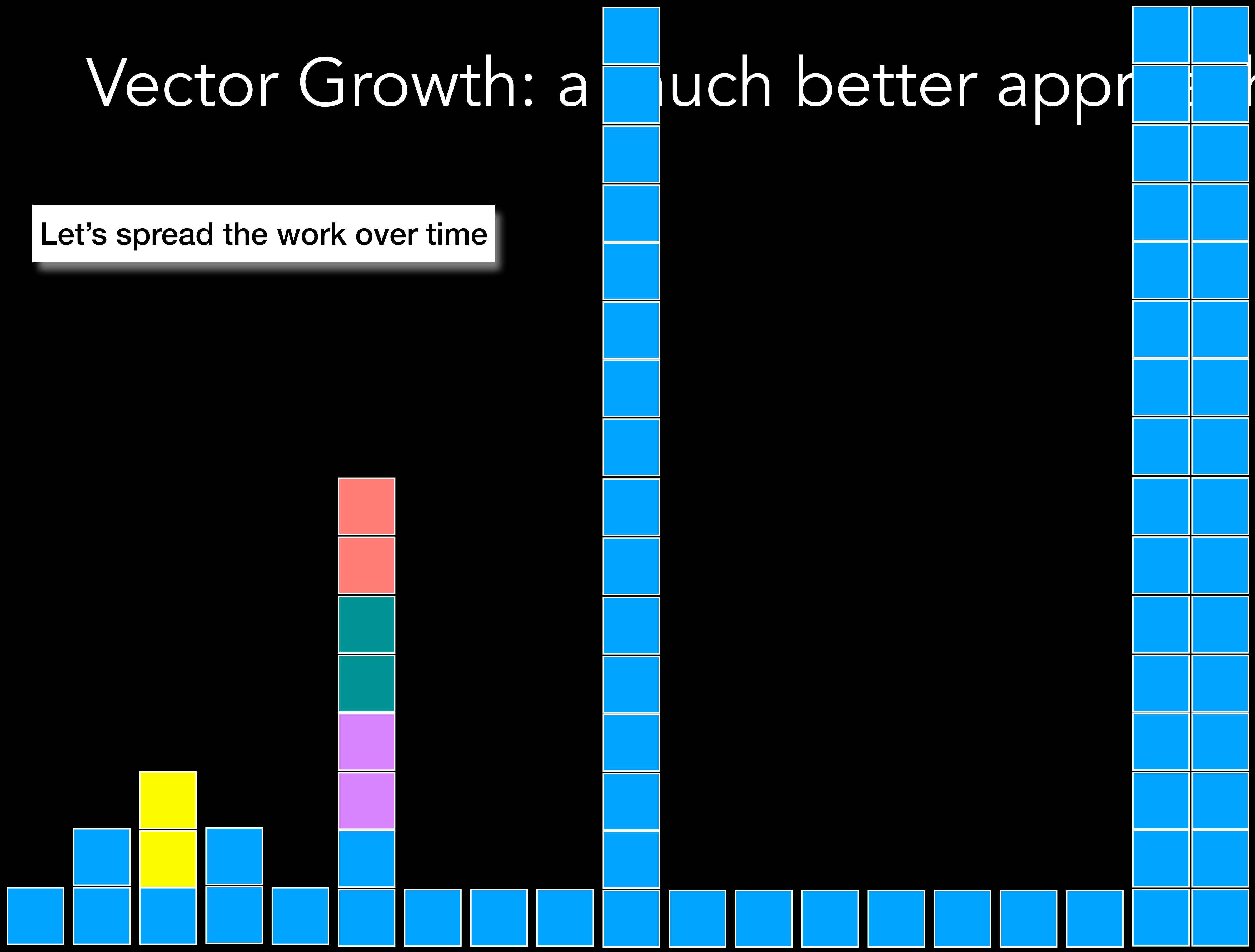
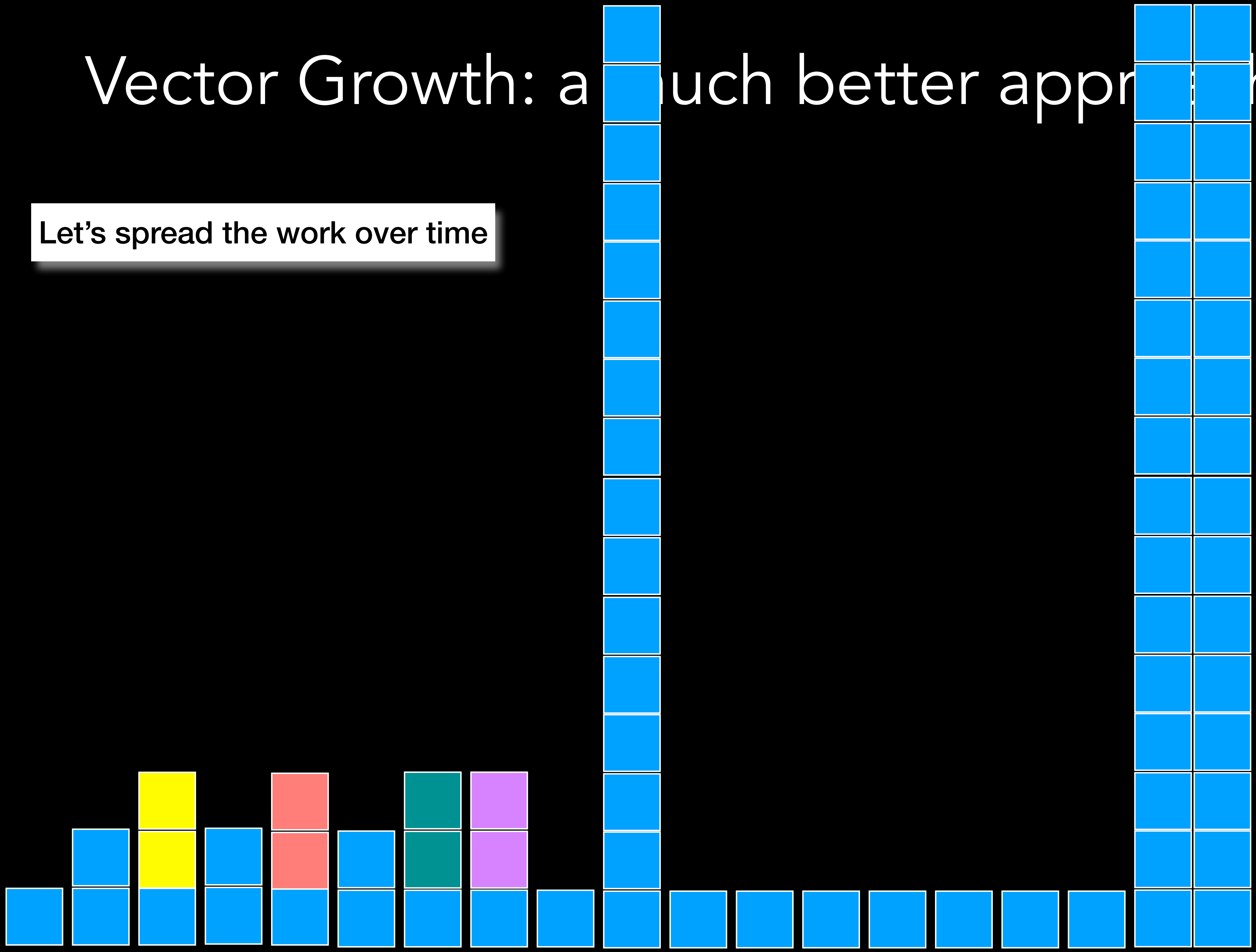
Vector Growth: a much better approach

Let’s spread the work over time



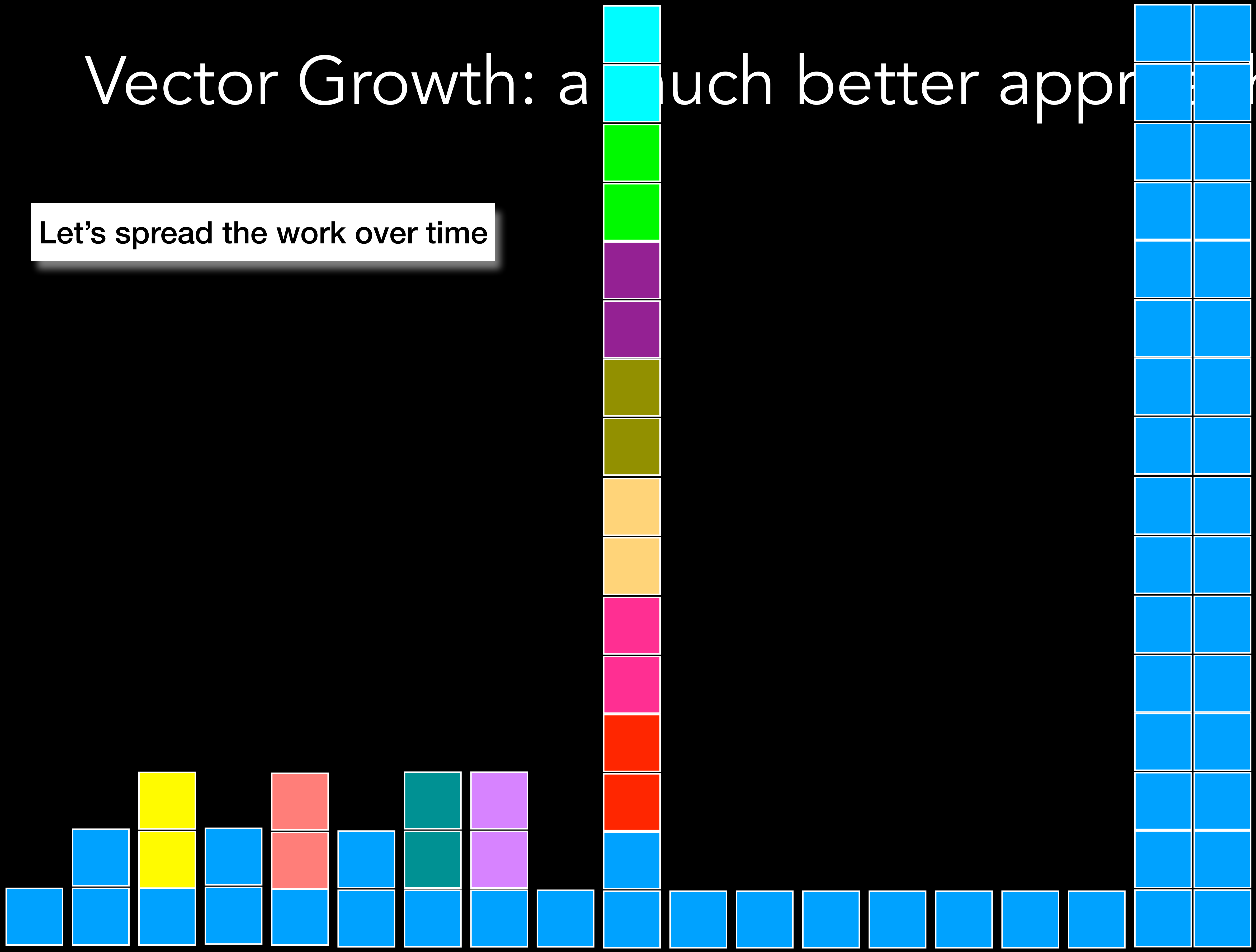
Vector Growth: a much better approach



Let’s spread the work over time

Vector Growth: a much better approach

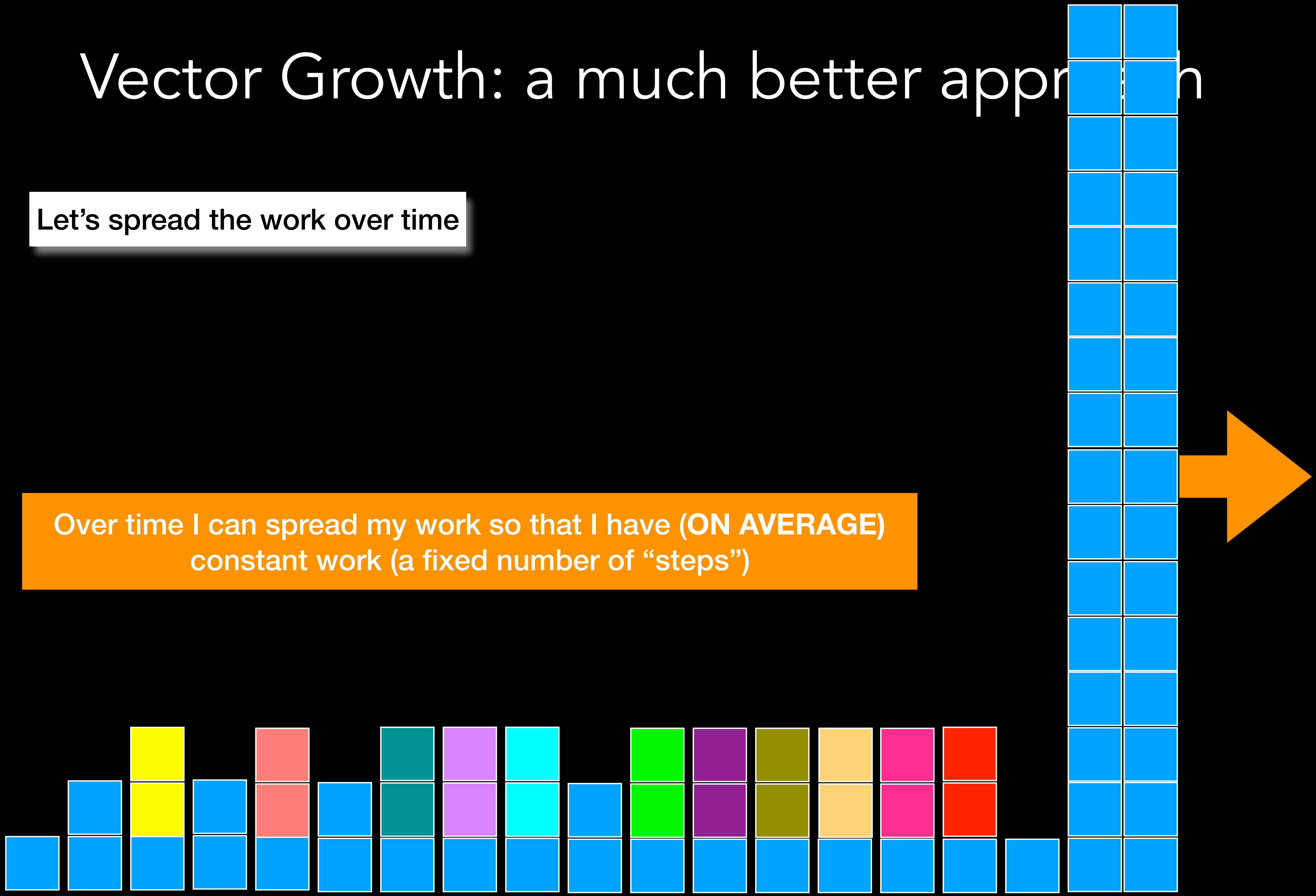
Let’s spread the work over time



Vector Growth: a much better appr h

Let’s spread the work over time

Over time I can spread my work so that I have **(ON AVERAGE)** constant work (a fixed number of “steps”)

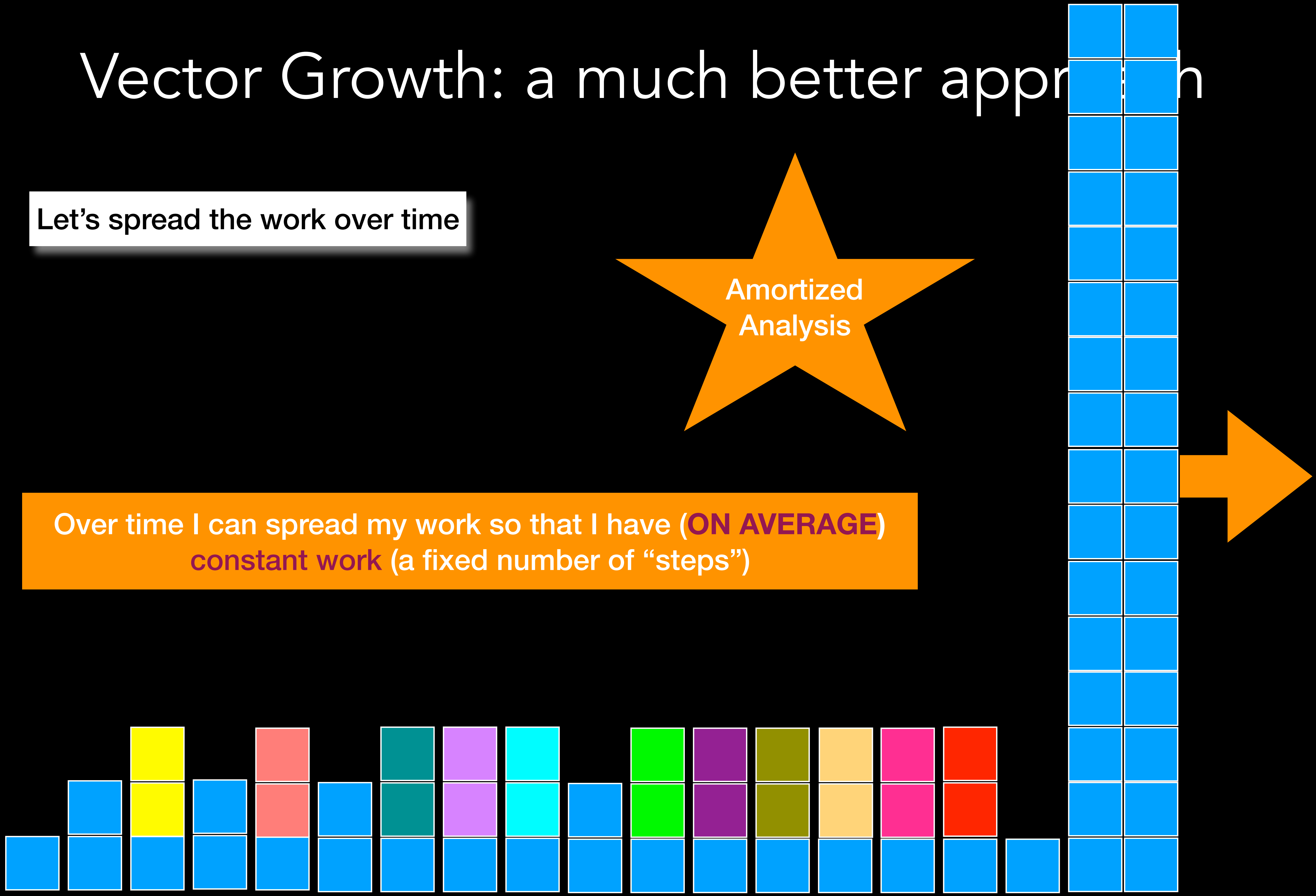


Vector Growth: a much better appr h

Let’s spread the work over time

Amortized Analysis

Over time I can spread my work so that I have (**ON AVERAGE**) constant work (a fixed number of “steps”)



Vector Growth summarized

If it grows by 1, push takes n^2 "*steps*"

If it grows by 2, push takes roughly half the"*steps*" over time (AMORTIZED ANALYSIS)

If it doubles its size, push takes constant work over time (AMORTIZED ANALYSIS)

A steadily shrinking Stack

Let's consider this application:

- Push the 524,288th element onto Stack which causes it to double it's size to 1,048,576
- Reading an input file
  - pop those that match
  - manipulate input record accordingly
  - repeat

A steadily shrinking Stack

Let’s consider this application:

- Push the 524,288th element onto Stack which causes it to double it’s size to 1,048,576
- Reading an input file
  - pop those that match
  - manipulate input record accordingly
  - repeat

How much I pop will depend on input

A steadily shrinking Stack

Assume a few matches at each iteration =>mostly empty stack but it will be around for a long time!

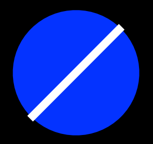
Let’s consider this application:

- Push the 524,288th element onto Stack which causes it to double it’s size to 1,048,576
- Reading an input file
    - pop those that match
    - manipulate input record accordingly
    - repeat

I will not shrink!

Useless memory waste

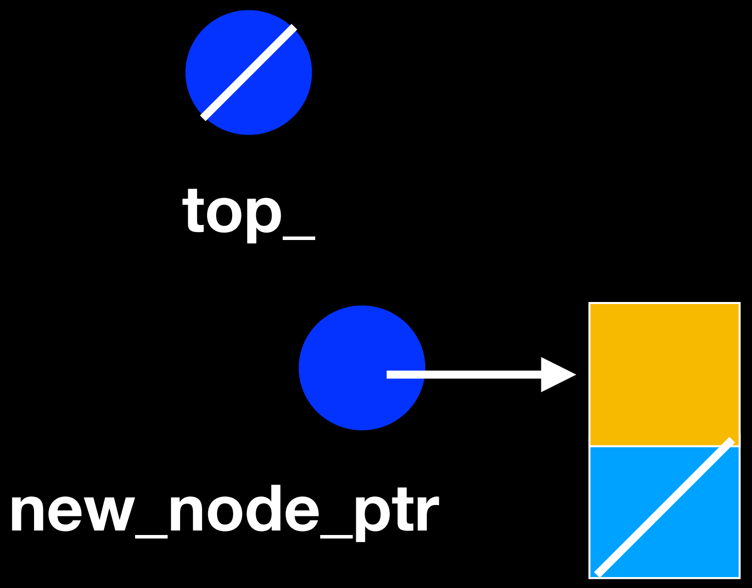
Linked Chain



top_

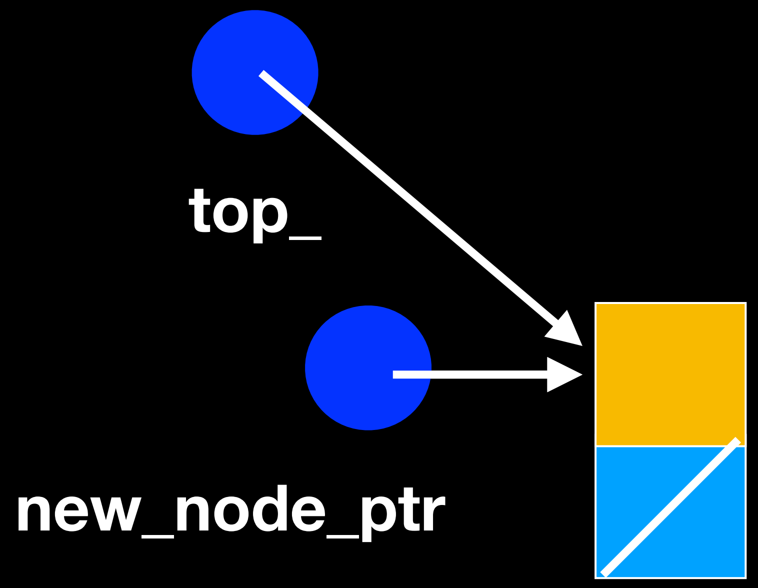
Linked Chain

push



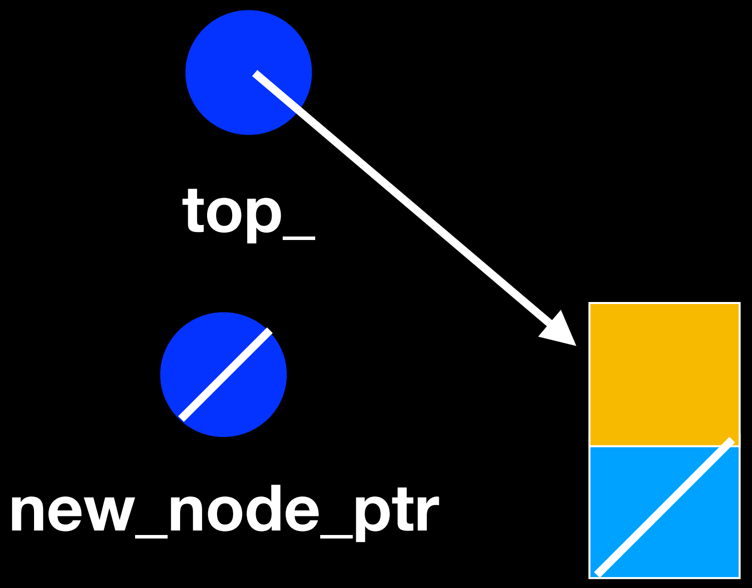
Linked Chain

push

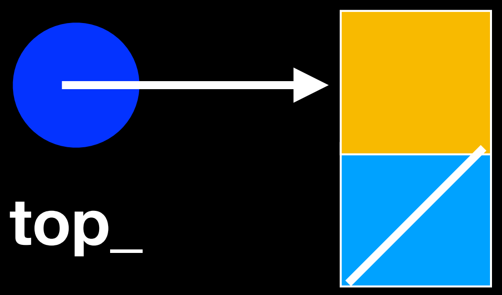


Linked Chain

push

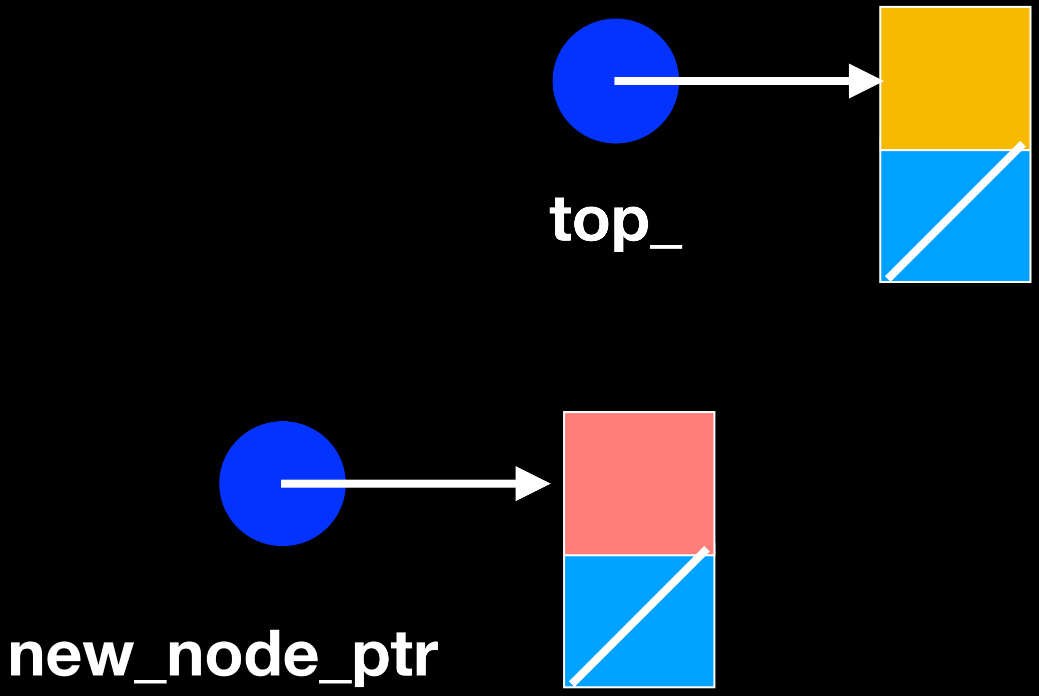


Linked Chain



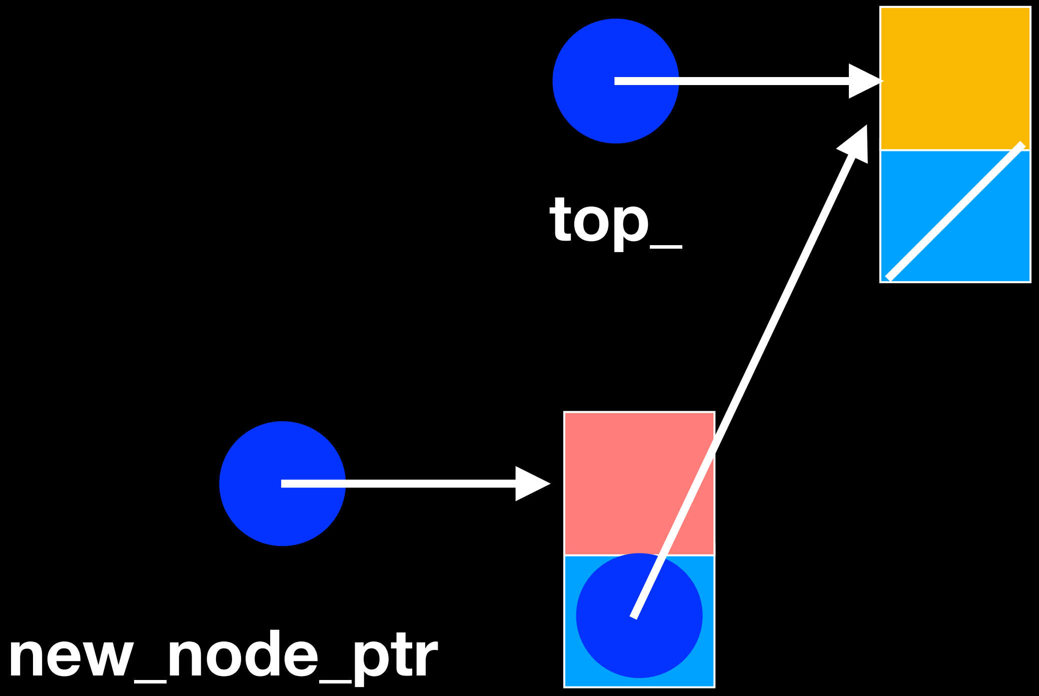
Linked Chain

push



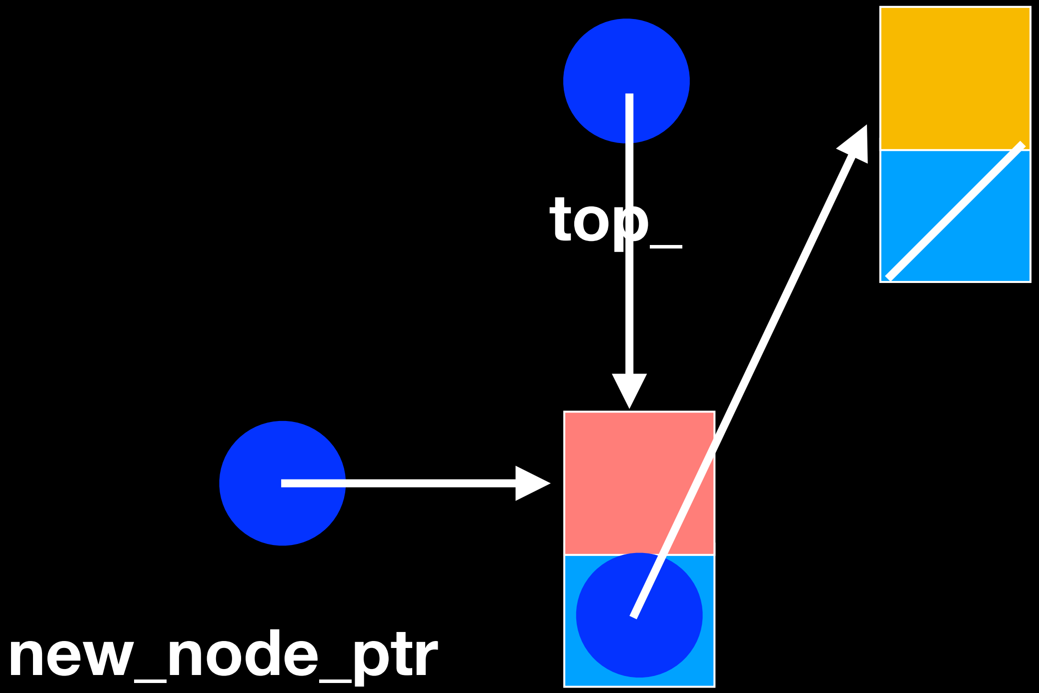
Linked Chain

push



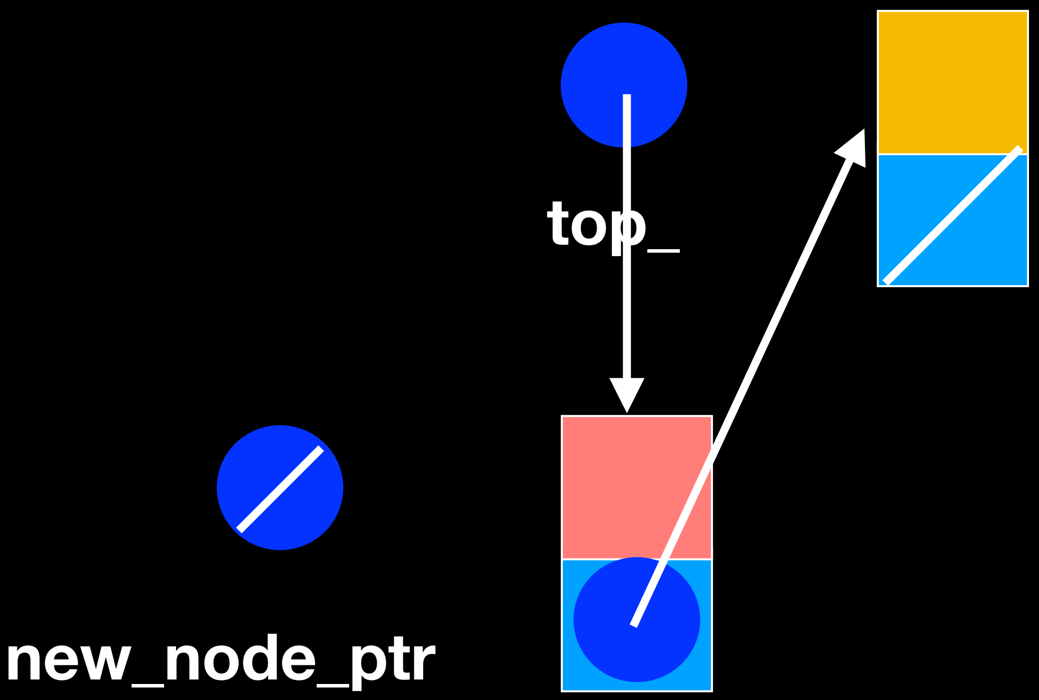
Linked Chain

push

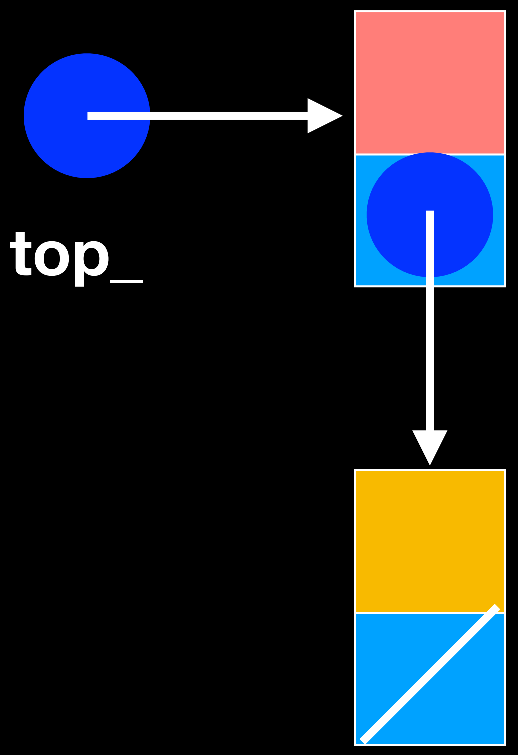


Linked Chain

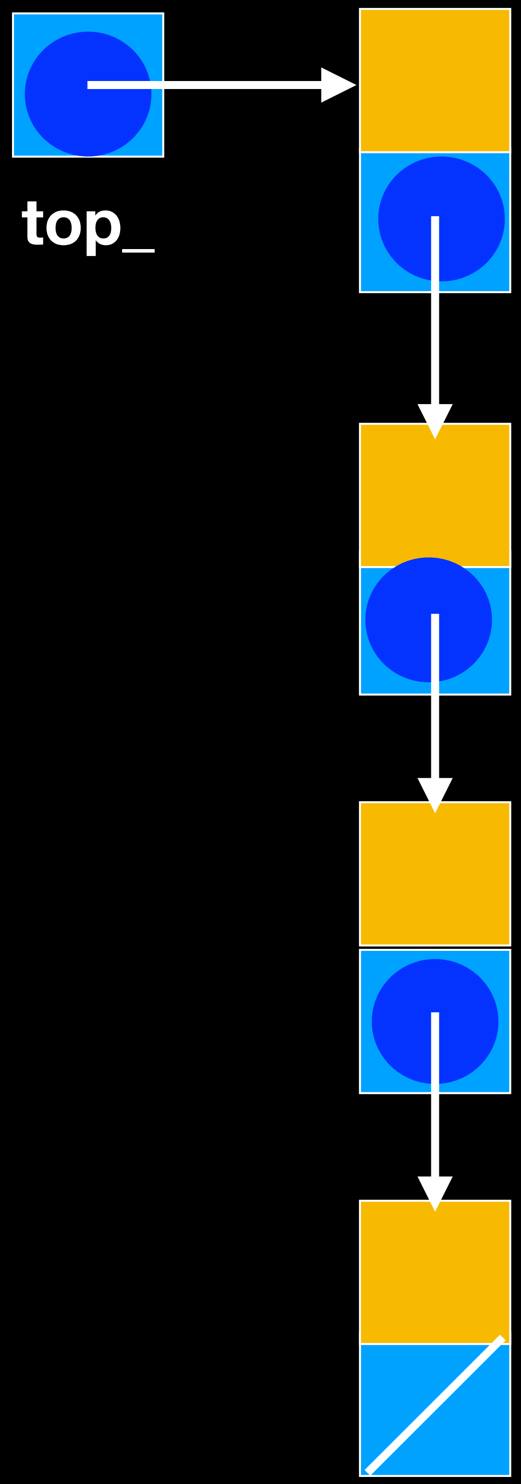
push



Linked Chain

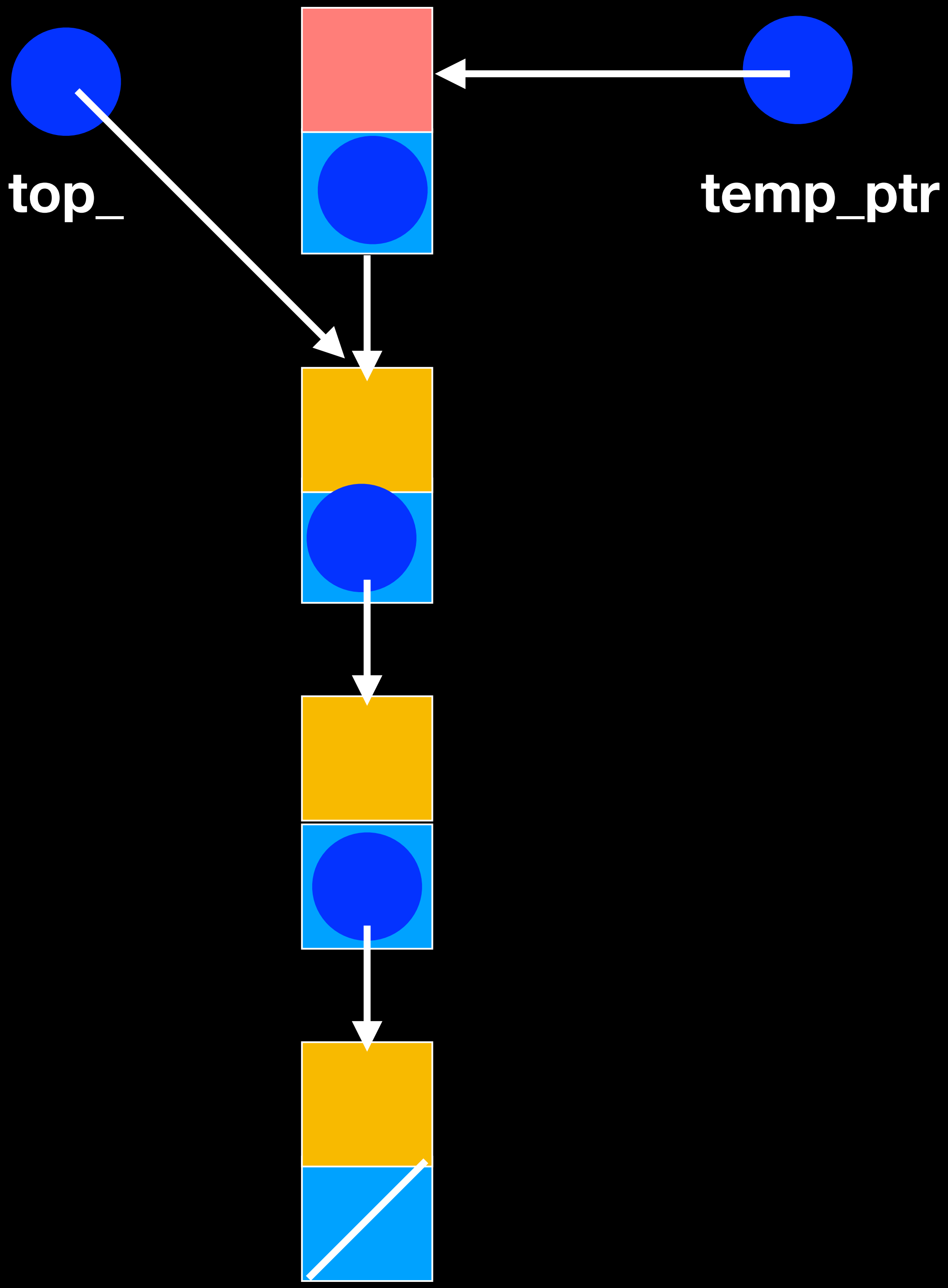


Linked Chain



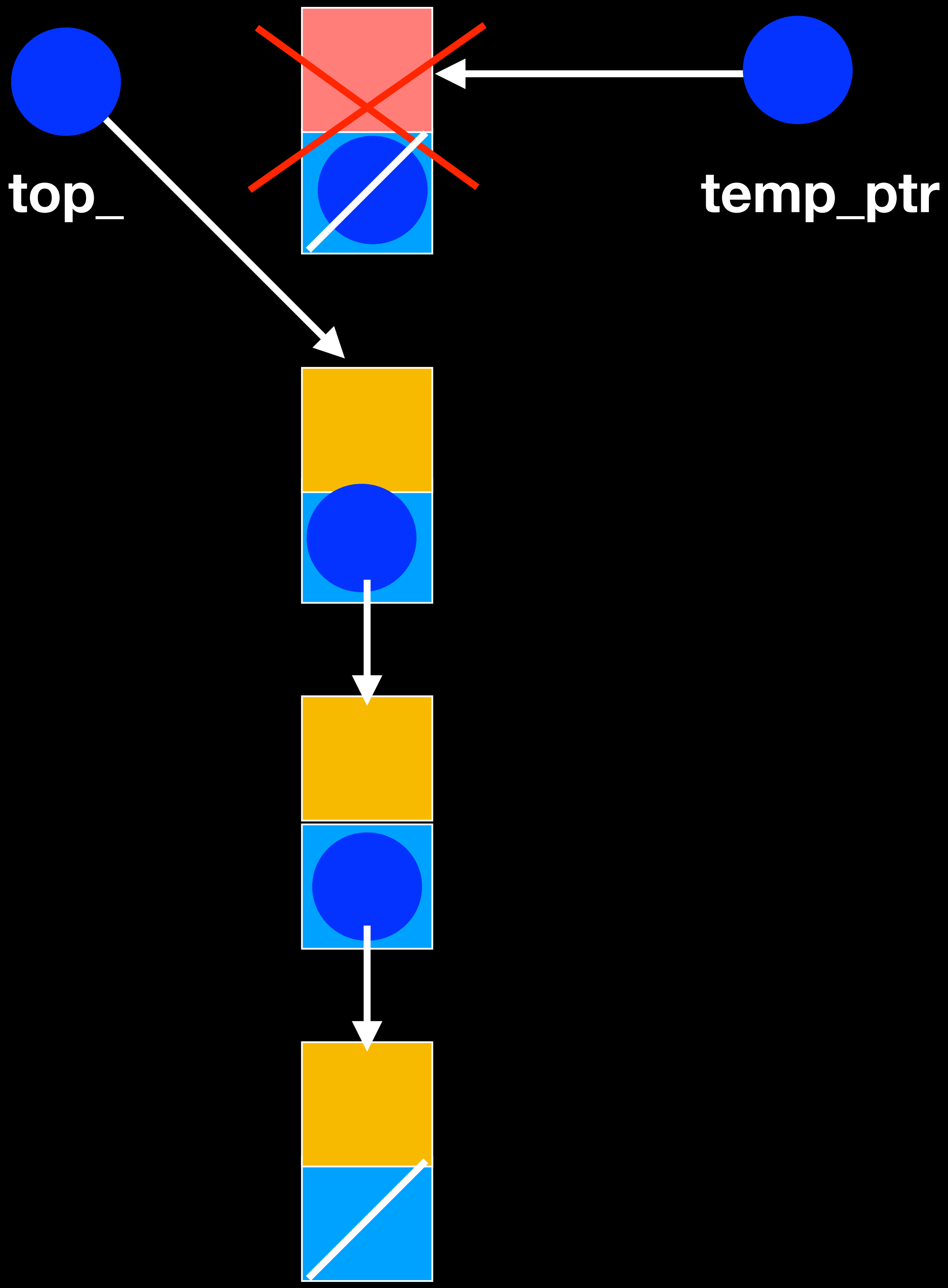
Linked Chain

pop



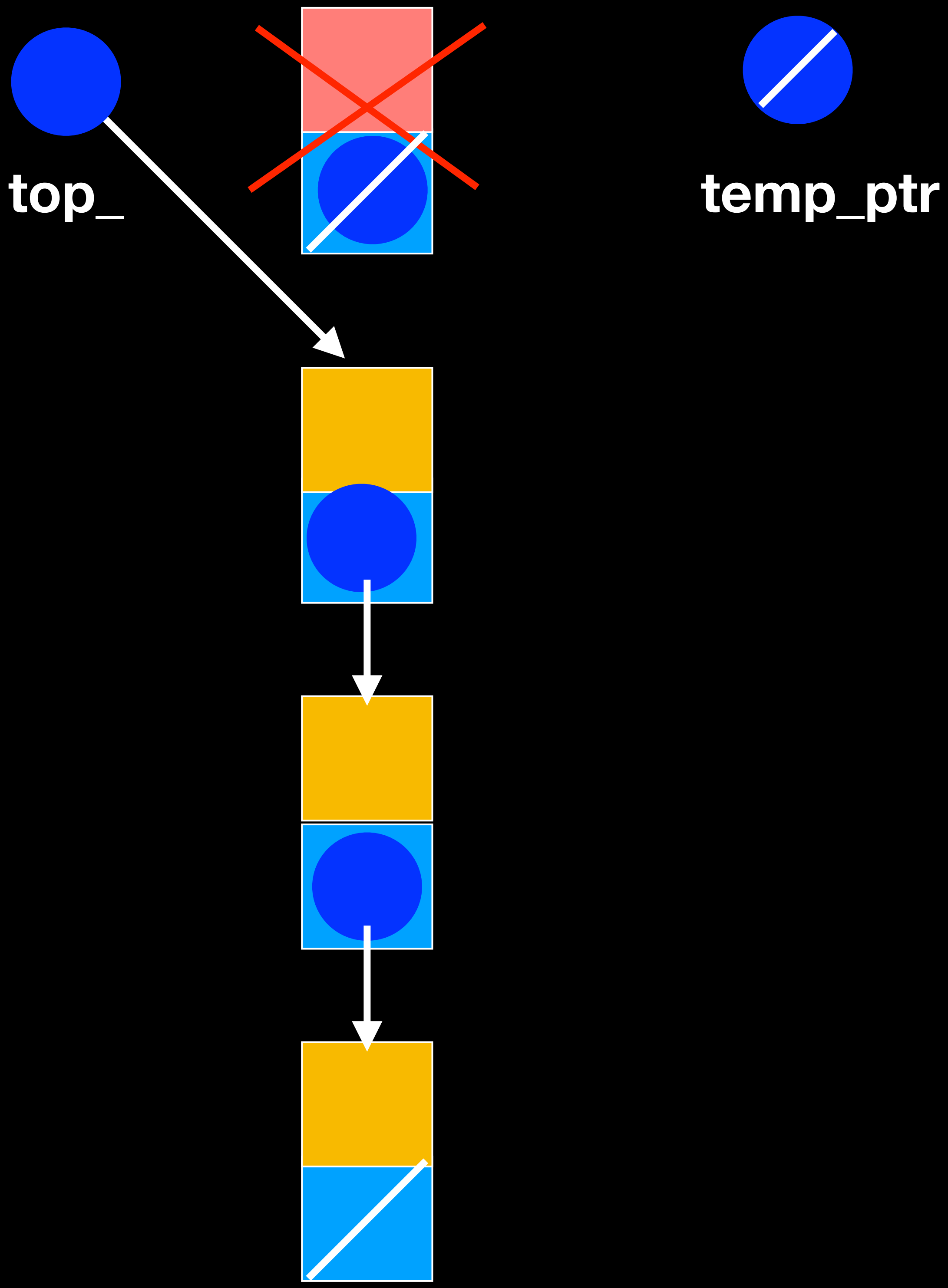
Linked Chain

pop

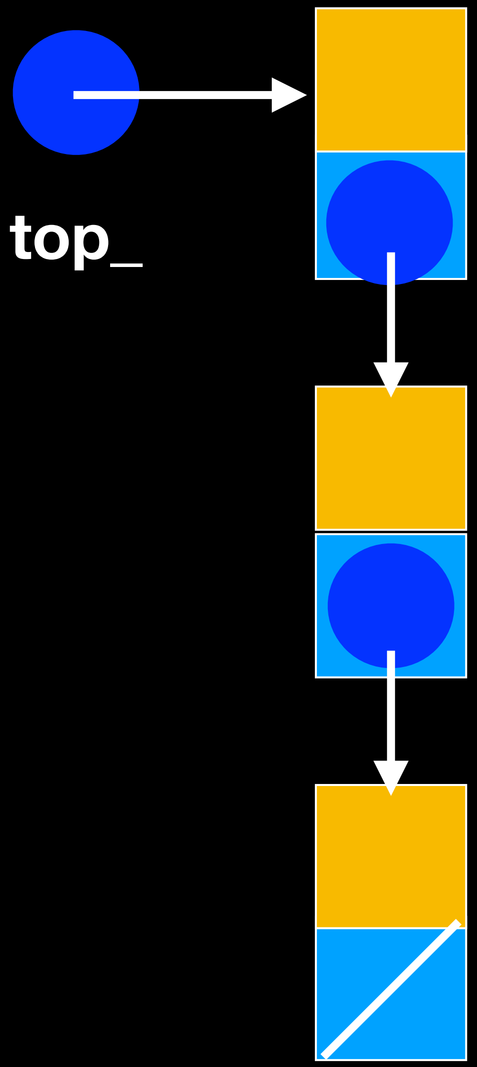


Linked Chain

pop



Linked Chain



Linked-Chain Analysis

Create new node + 1 data-item assignment + a few pointer assignment = 1 "*step*"

Fixed amount of work

`size` : 1 "*step*"
`isEmpty`: 1 "*step*"
`push`: 1 "*step*"
`pop` : 1 "*step*"
`top` : 1 "*step*"

GREAT!!!! And there is no "Except" case here, always guaranteed fixed amount of work!

To summarize

Array: constant amount of work for push and pop, but size is bounded

Vector: size is unbounded but

- -If it grows by 1, push takes n^2 "*steps*"
- -If it grows by 2, push roughly half the"*steps*" over time (AMORTIZED ANALYSIS)
- -If it grows doubles, push takes constant work over time (AMORTIZED ANALYSIS)

Linked-Chain: constant amount of work for push and pop and size in unbounded

Implement Stack ADT

```
#ifndef STACK_H_
#define STACK_H_

template<class ItemType>
class Stack
{

public:
    Stack();
    void push(const ItemType& newEntry); // adds an element to top of stack
    void pop(); // removes element from top of stack
    ItemType top() const; // returns a copy of element at top of stack
    int size() const; // returns the number of elements in the stack
    bool isEmpty() const; // returns true if no elements on stack false otherwise

private:
    Node<ItemType>* top_; // Pointer to top of stack
    int itemCount;        // number of items currently on the stack


};    //end Stack

#include "Stack.cpp"
#endif // STACK_H_
```