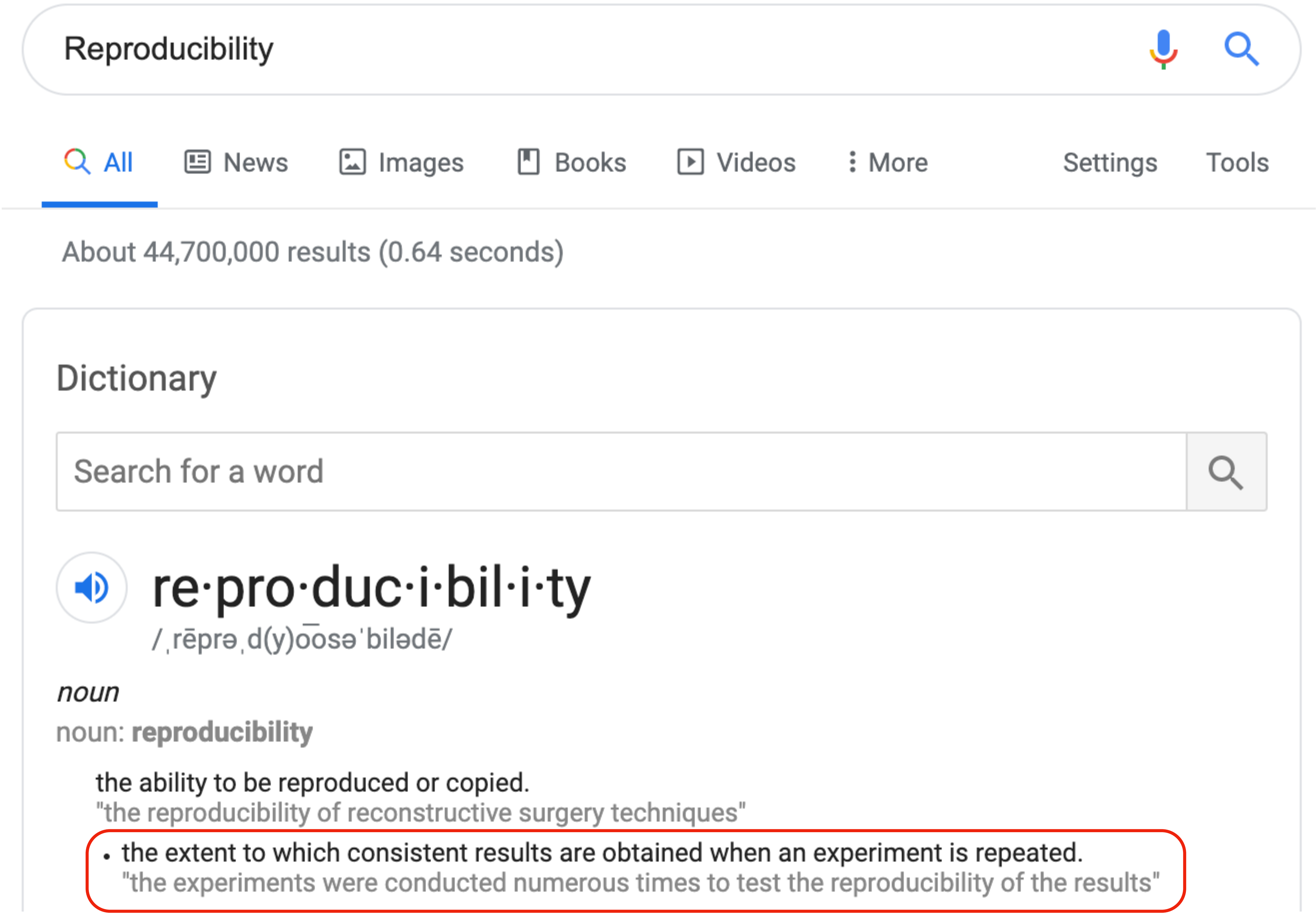
[320] Reproducibility 2

Yiyin Shen



About 44,700,000 results (0.64 seconds)

Dictionary

re·pro·duc·i·bil·i·ty

/ˌrēprəˌd(y)o͞osəˈbilədē/

noun

noun: **reproducibility**

the ability to be reproduced or copied.
"the reproducibility of reconstructive surgery techniques"

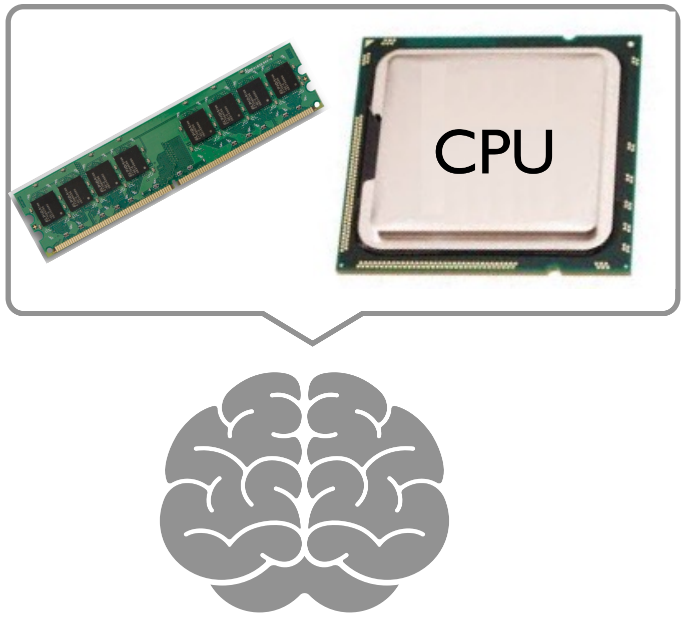
- the extent to which consistent results are obtained when an experiment is repeated.
  "the experiments were conducted numerous times to test the reproducibility of the results"

Discuss: *how might we define "reproducibility" for a data scientist?*

Big question: *will my program run on someone else's computer?*
(not necessarily written in Python)

Things to match:

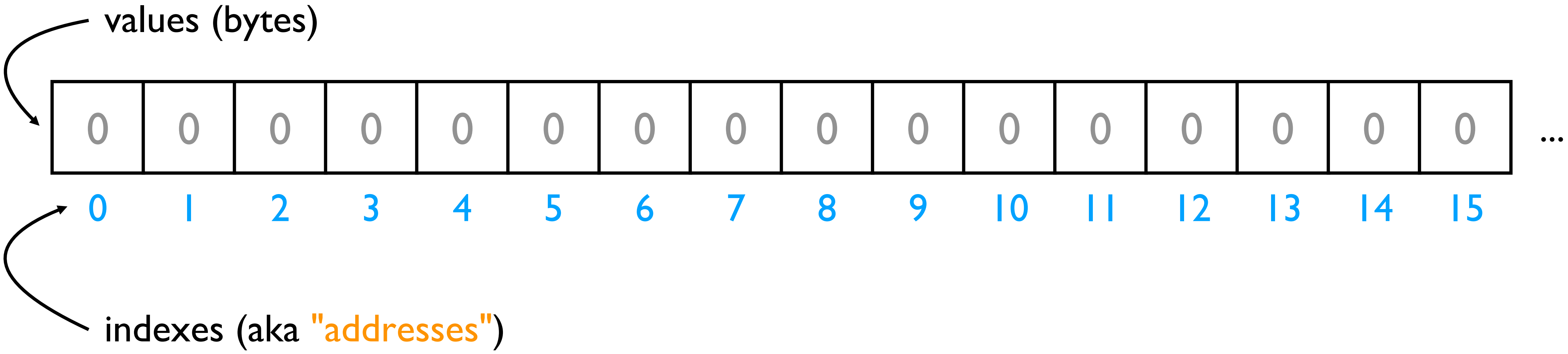
1. Hardware
2. Operating System
3. Dependencies



Hardware: Mental Model of Process Memory

Imagine...

- one huge list, **per each** ~~running program~~ **process**, called **"address space"**
- every entry in the list is an integer between 0 and 255 (aka a "byte")



values (bytes)

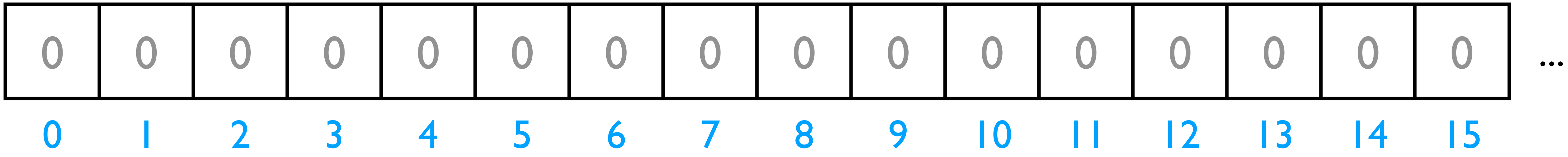
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	...
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	

indexes (aka "addresses")

How can we use one giant list to handle the following?

- multiple lists
- variables and other references
- strings
- code

data



0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	…

Is this really all we have for state?

How can we use one giant list to handle the following?

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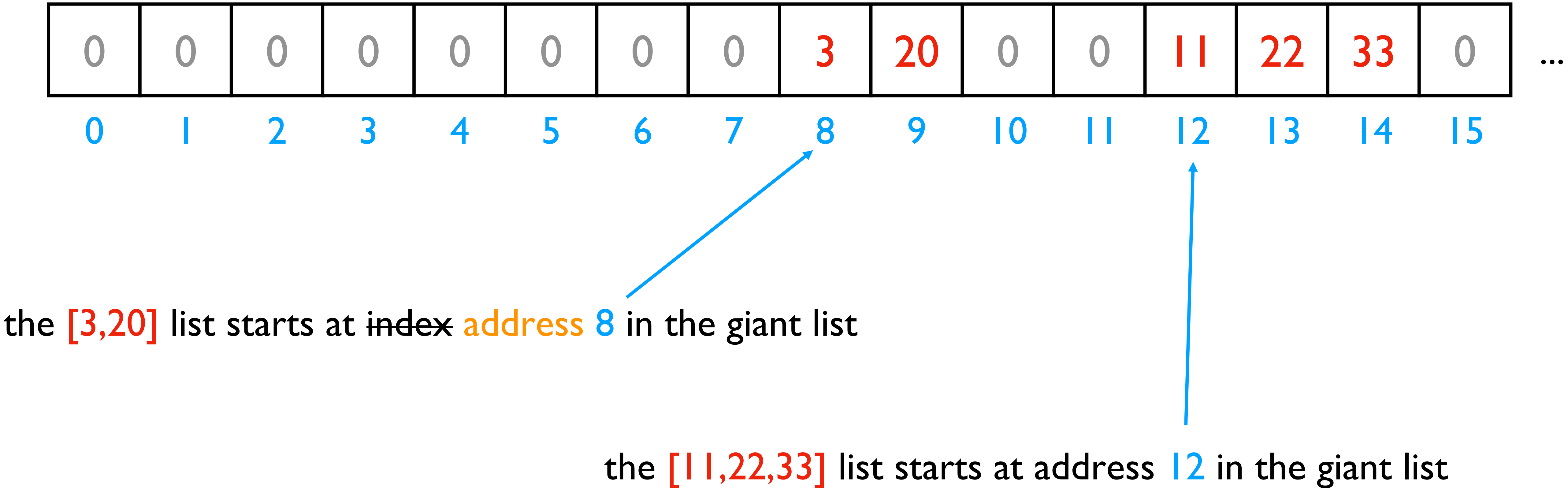


0	0	0	0	0	0	0	0	3	20	0	0	11	22	33	0	...
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	

the [3,20] list starts at ~~index~~ address 8 in the giant list

the [11,22,33] list starts at address 12 in the giant list

How can we use one giant list to handle the following?

- multiple lists
- variables and other references
- strings
- code

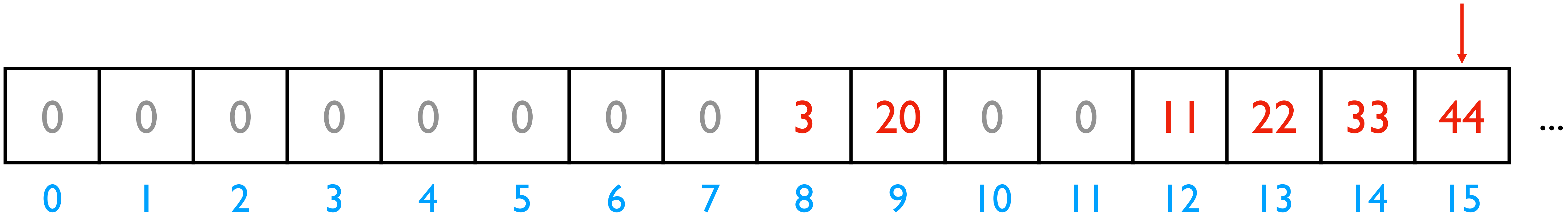
0	0	0	0	0	0	0	0	3	20	0	0	11	22	33	0	...
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	

```
# fast
L2.append(44)
```

implications for performance...

How can we use one giant list to handle the following?

- multiple lists
- variables and other references
- strings
- code



0	0	0	0	0	0	0	0	3	20	0	0	11	22	33	44	...
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	

implications for performance...

```
# fast
L2.append(44)
```

How can we use one giant list to handle the following?

- multiple lists
- variables and other references
- strings
- code

0	0	0	0	0	0	0	0	3	20	0	0	11	22	33	44	...
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	

implications for performance...

```
# fast
L2.append(44)

# slow
L2.pop(0)
```

How can we use one giant list to handle the following?

- multiple lists
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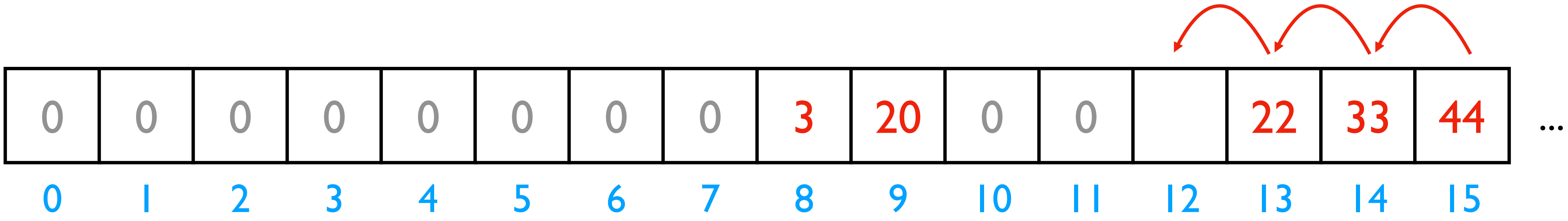
- strings
- code



0	0	0	0	0	0	0	0	3	20	0	0		22	33	44	...
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	

implications for performance...

```
# fast
L2.append(44)

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L2.pop(0)
```

How can we use one giant list to handle the following?

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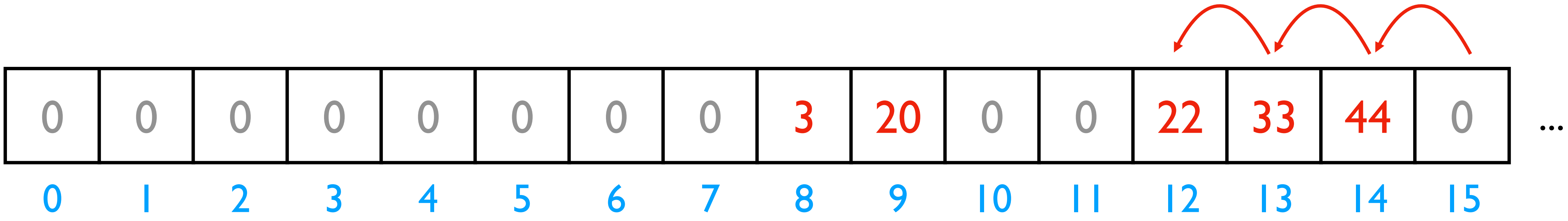

0	0	0	0	0	0	0	0	3	20	0	0	22	33	44	0	...
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	

We'll think more rigorously about performance in CS 320 (big-O notation)

```
# fast
L2.append(44)

# slow
L2.pop(0)
```

How can we use one giant list to handle the following?

- multiple lists
- variables and other references
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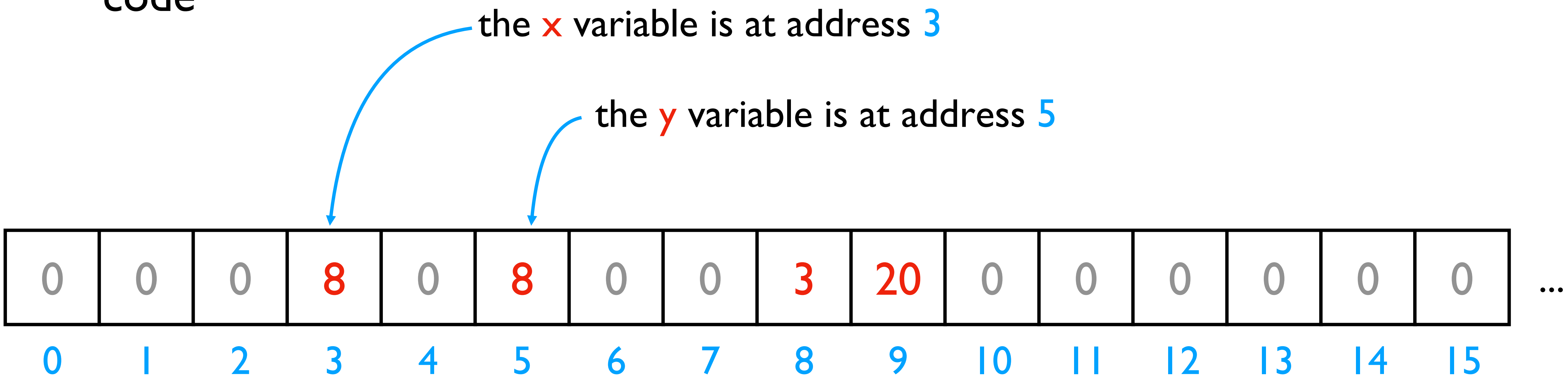
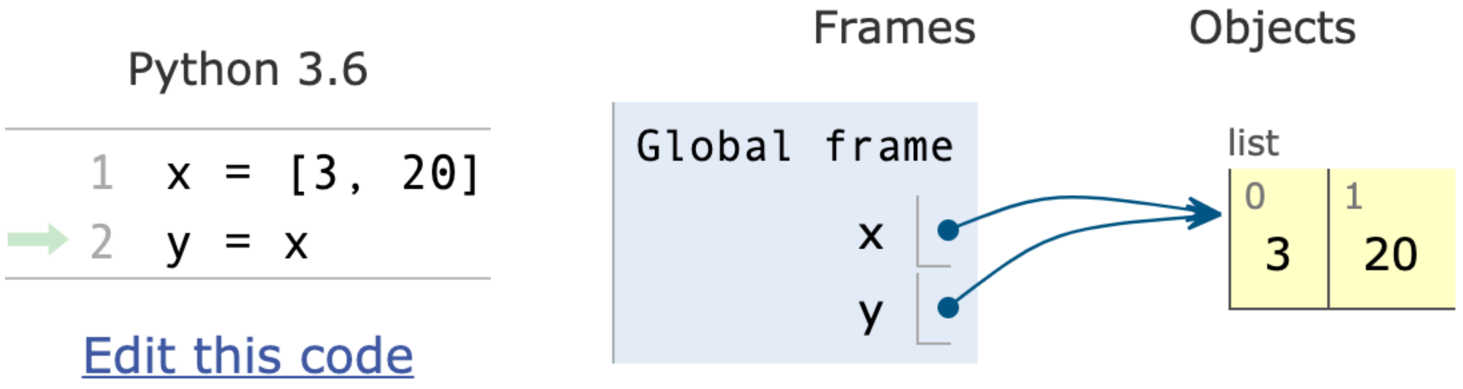
- code



the x variable is at address 3

the y variable is at address 5

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
0	0	0	8	0	8	0	0	3	20	0	0	0	0	0	0	...



Python 3.6

```
x = [3, 20]
y = x
```

PythonTutor's visualization

How can we use one giant list to handle the following?

- multiple lists
- variables and other references
- strings
- code

discuss: how?

0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	...
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	

Is this really all we have for state?

How can we use one giant list to handle the following?

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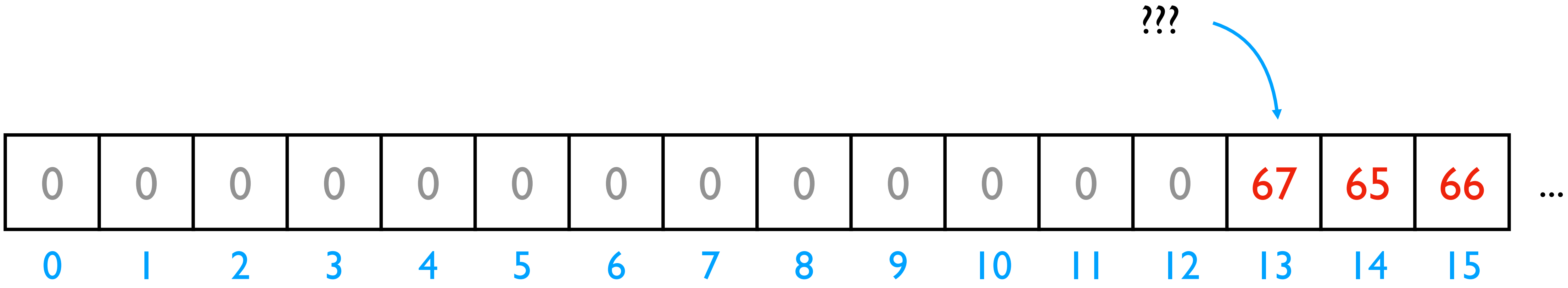

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
0	0	0	0	0	0	0	0	0	0	0	0	0	67	65	66	...

encoding:

code	letter
65	A
66	B
67	C
68	D
...	...

```
f = open("file.txt", encoding="utf-8")
```

How can we use one giant list to handle the following?

- multiple lists
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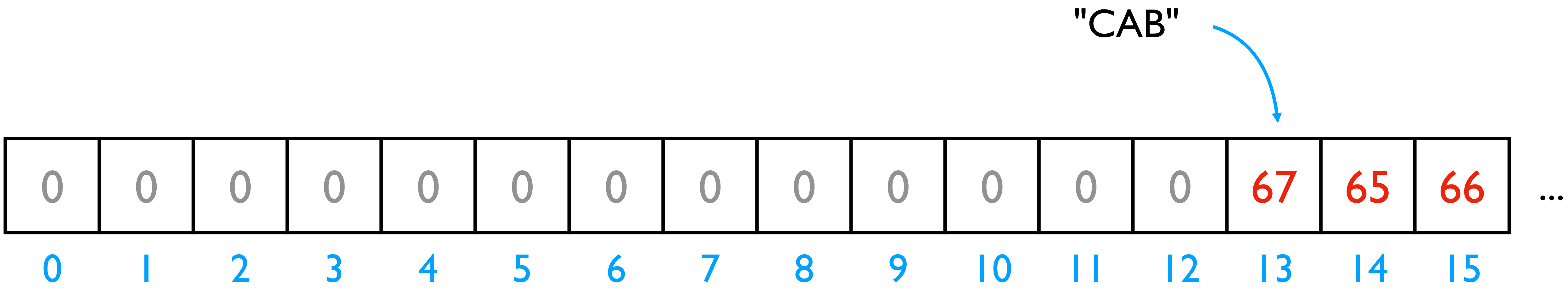
- strings
- code



"CAB"

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
0	0	0	0	0	0	0	0	0	0	0	0	0	67	65	66	...

encoding:

code	letter
65	A
66	B
67	C
68	D
...	...

```
f = open("file.txt", encoding="utf-8")
```

How can we use one giant list to handle the following?

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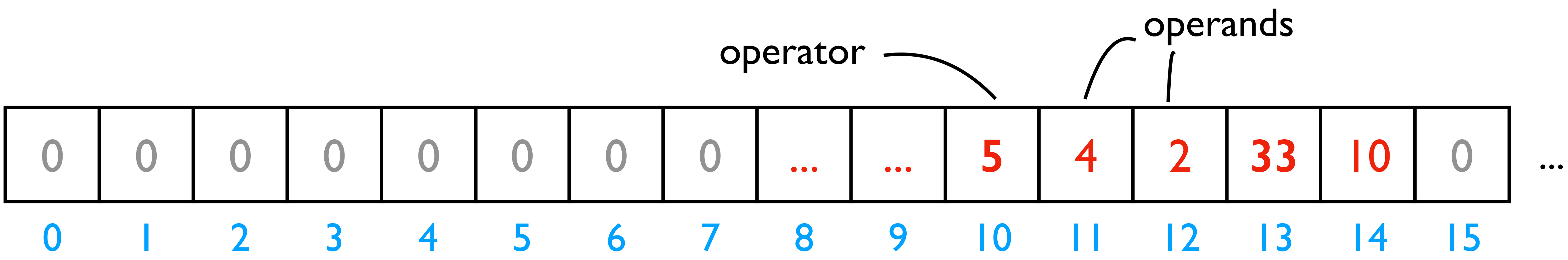
- code

```
i = 0
while ????:
   i += 2
   # what line next?
```



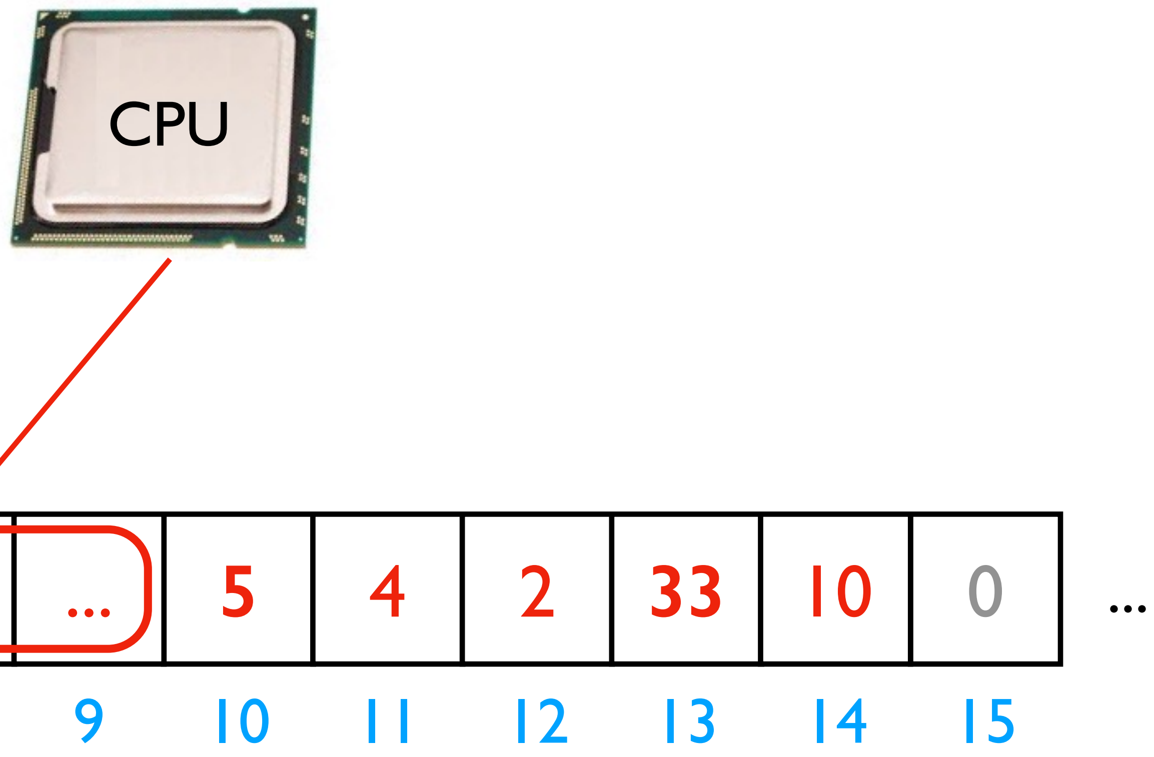
Instruction Set

code	operation
5	ADD
8	SUB
33	JUMP
...	...

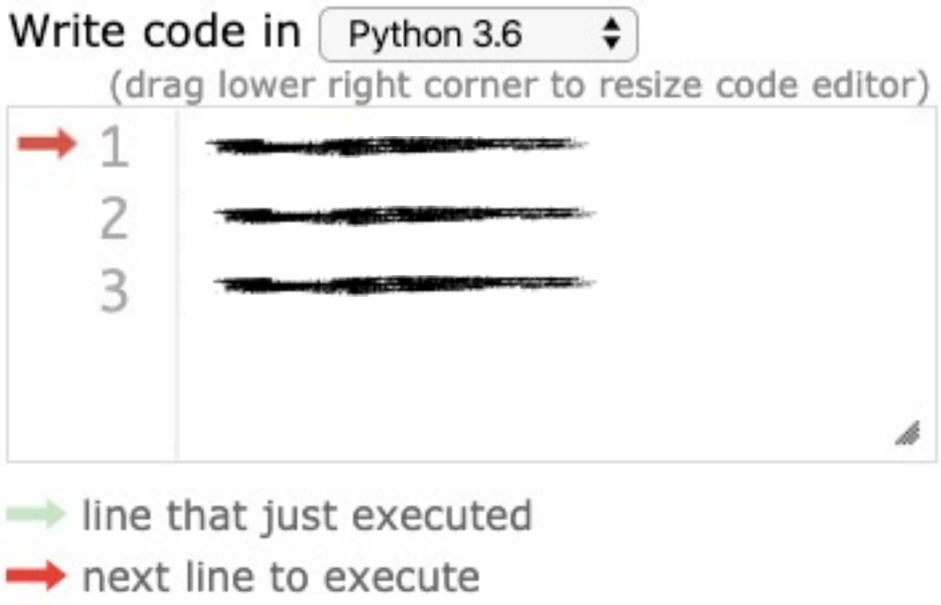
Hardware: Mental Model of CPU

CPUs interact with memory:

- keep track of what instruction we're on
- understand instruction codes
- much more



0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
0	0	0	0	0	0	0	0	...	...	5	4	2	33	10	0	...


Write code in Python 3.6

(drag lower right corner to resize code editor)

```
[redacted]
```

line that just executed

next line to execute

Instruction Set

code	operation
5	ADD
8	SUB
33	JUMP
...	...

Hardware: Mental Model of CPU

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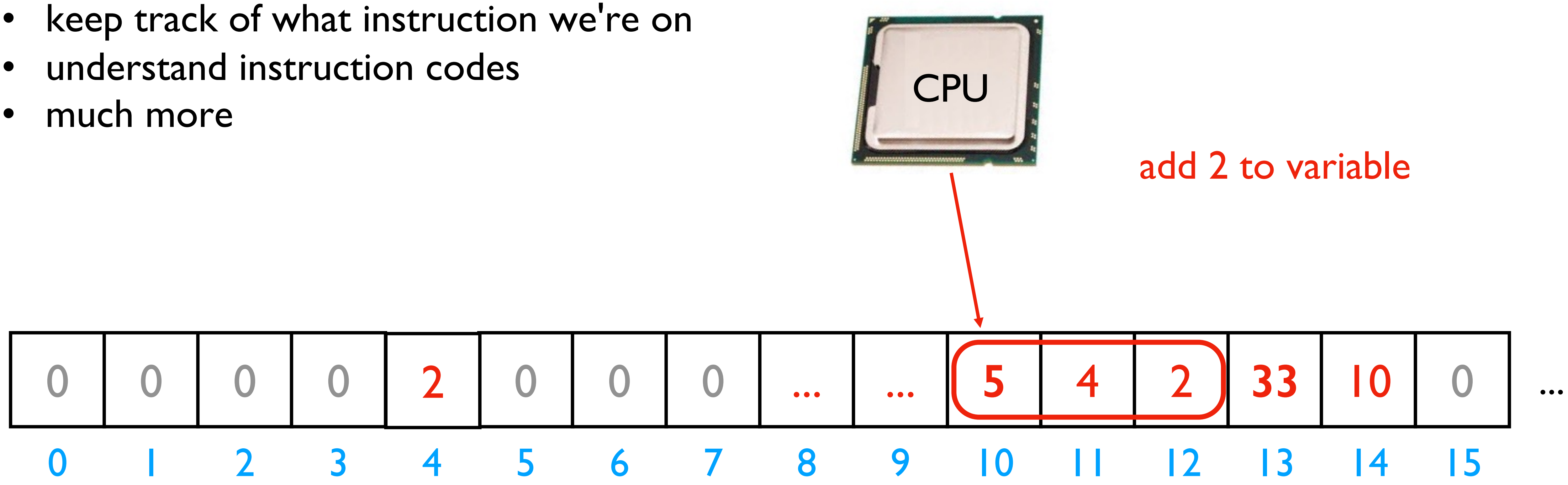
- much more



0	0	0	0	2	0	0	0	...	...	5	4	2	33	10	0	...
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	

Instruction Set

code	operation
5	ADD
8	SUB
33	JUMP
...	...

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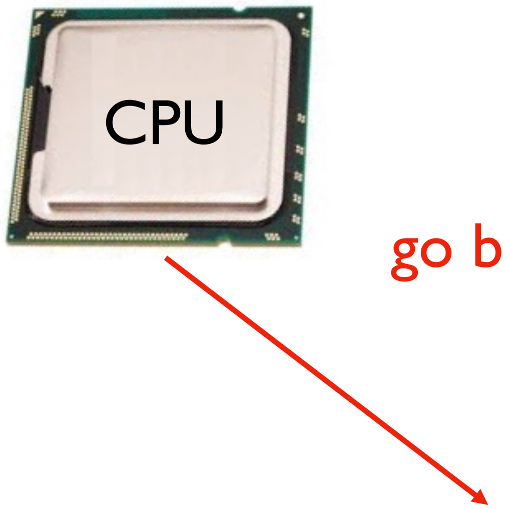

go back to top of loop

0	0	0	0	2	0	0	0	...	...	5	4	2	33	10	0	...
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	

Instruction Set

code	operation
5	ADD
8	SUB
33	JUMP
...	...

Hardware: Mental Model of CPU

CPUs interact with memory:

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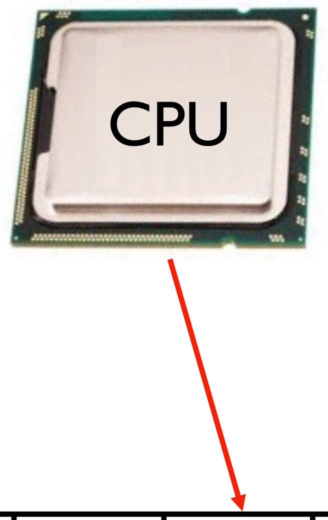


0	0	0	0	2	0	0	0	...	...	5	4	2	33	10	0	...
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	

Instruction Set

code	operation
5	ADD
8	SUB
33	JUMP
...	...

Hardware: Mental Model of CPU

discuss: what would happen if a CPU tried to execute an instruction for a different CPU?

0	0	0	0	0	0	0	0	...	...	5	4	2	33	10	0	...
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	

Instruction Set for CPU X

code	operation
5	ADD
8	SUB
33	JUMP
...	...

Instruction Set for CPU Y

code	operation
5	SUB
8	ADD
33	undefined
...	...

Hardware: Mental Model of CPU

a CPU can only run programs that
use instructions it understands!

0	0	0	0	0	0	0	0	...	...	5	4	2	33	10	0	...
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	

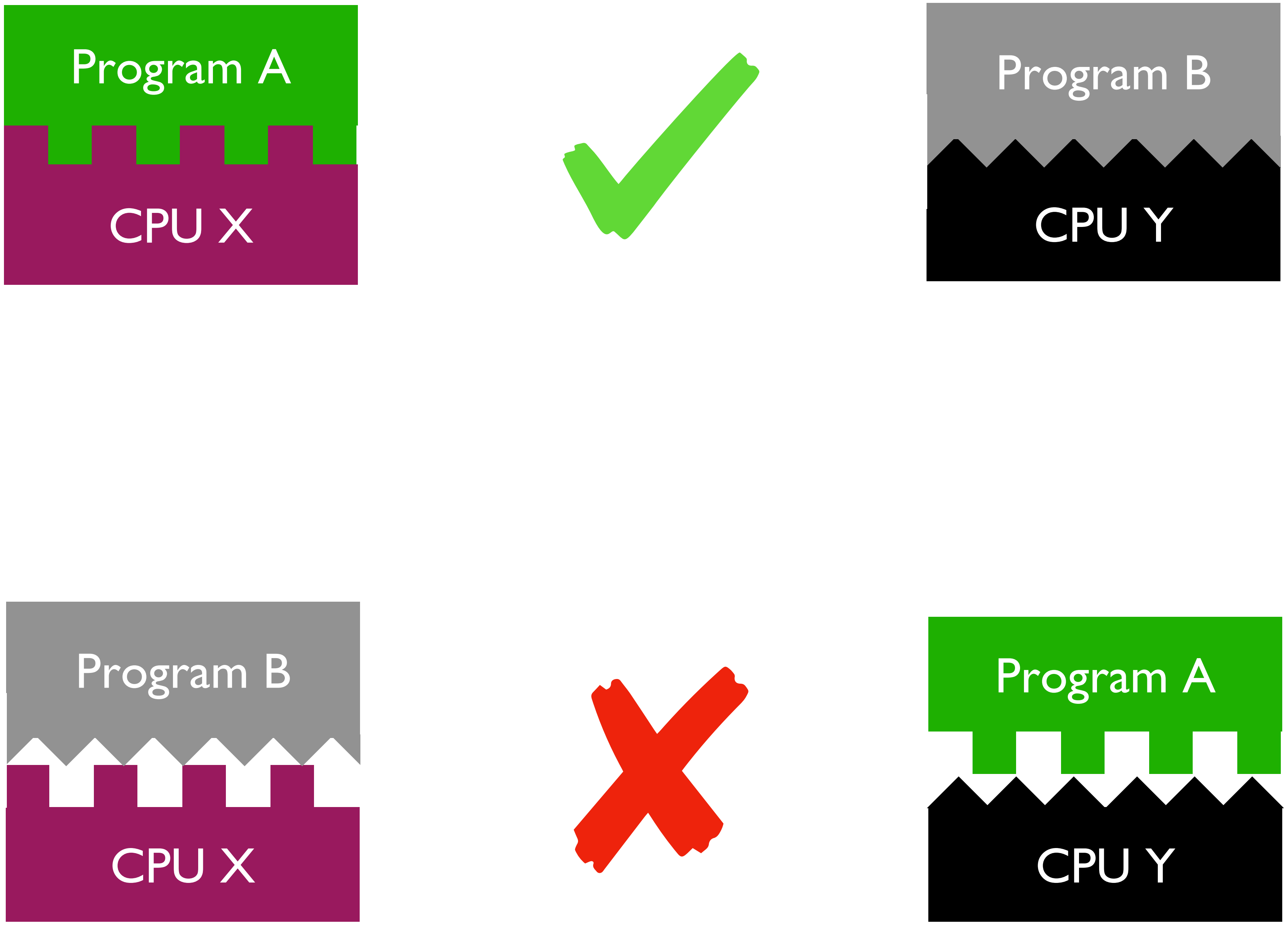
Instruction Set for CPU X

code	operation
5	ADD
8	SUB
33	JUMP
...	...

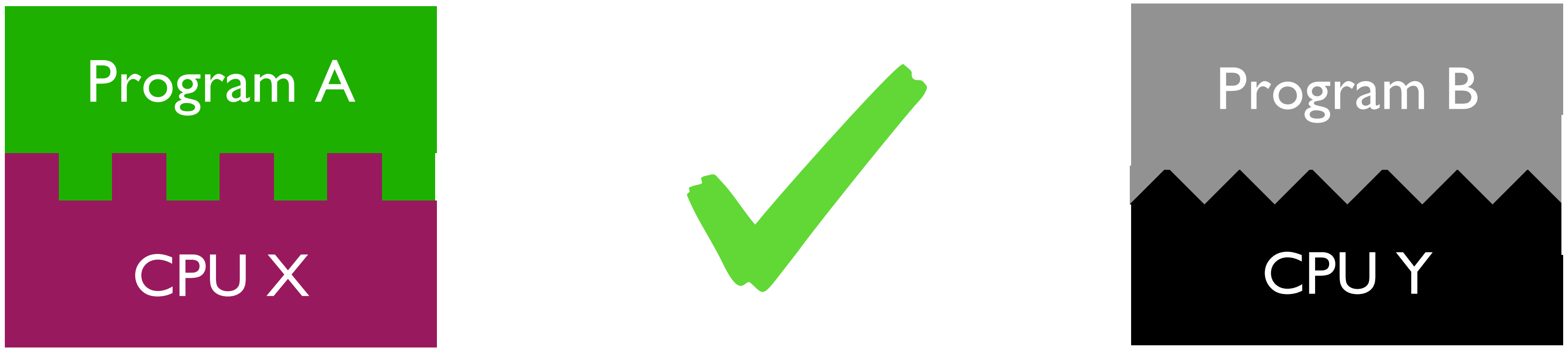
Instruction Set for CPU Y

code	operation
5	SUB
8	ADD
33	undefined
...	...

A Program and CPU need to "fit"



A Program and CPU need to "fit"



Program A

CPU X

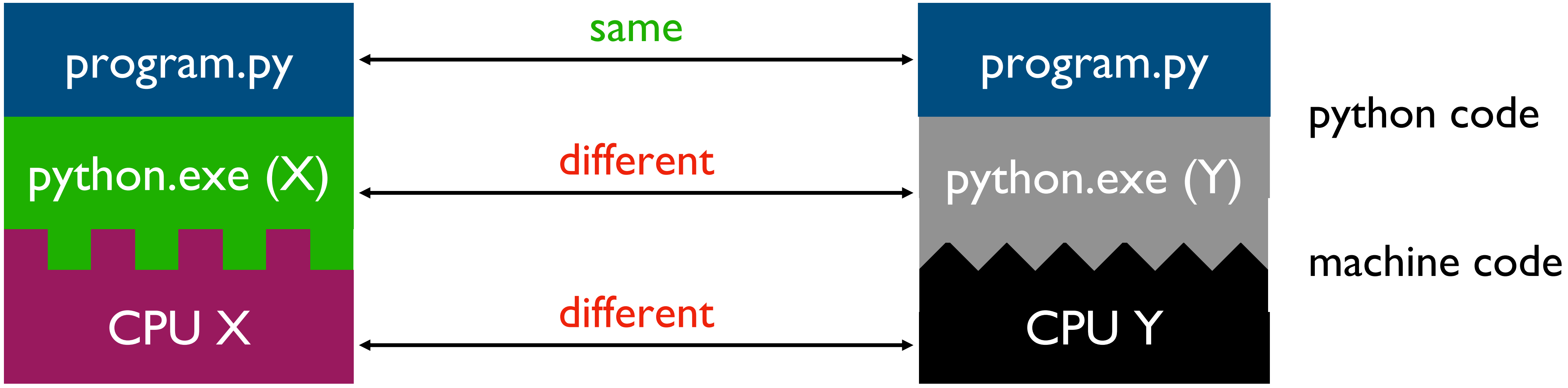
✓

Program B

CPU Y

why haven't we noticed this yet for our Python programs?

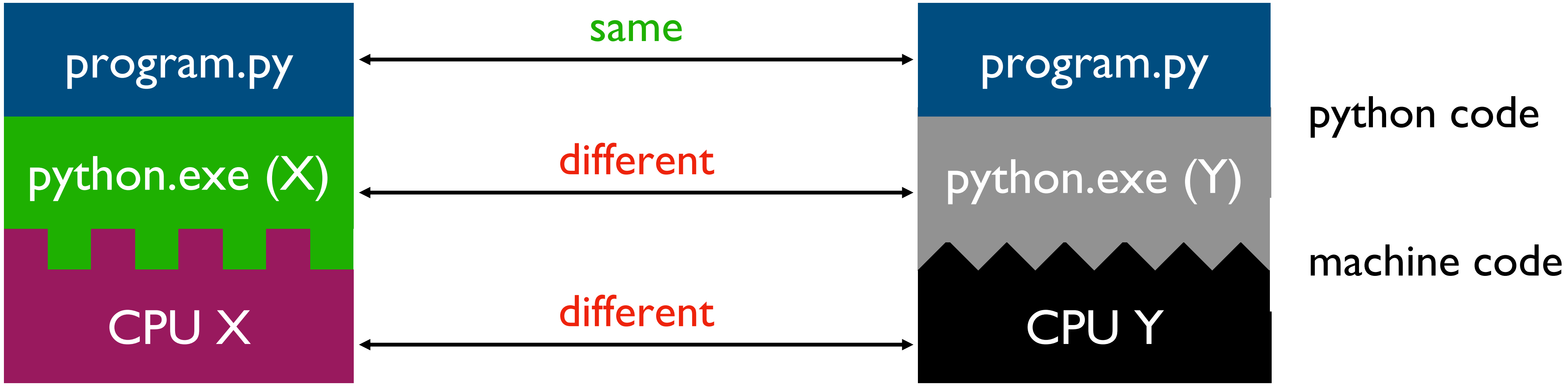
Interpreters



Interpreters (such as python.exe) make it easier to run the same code on different machines

A compiler is another tool for running the same code on different CPUs

Interpreters



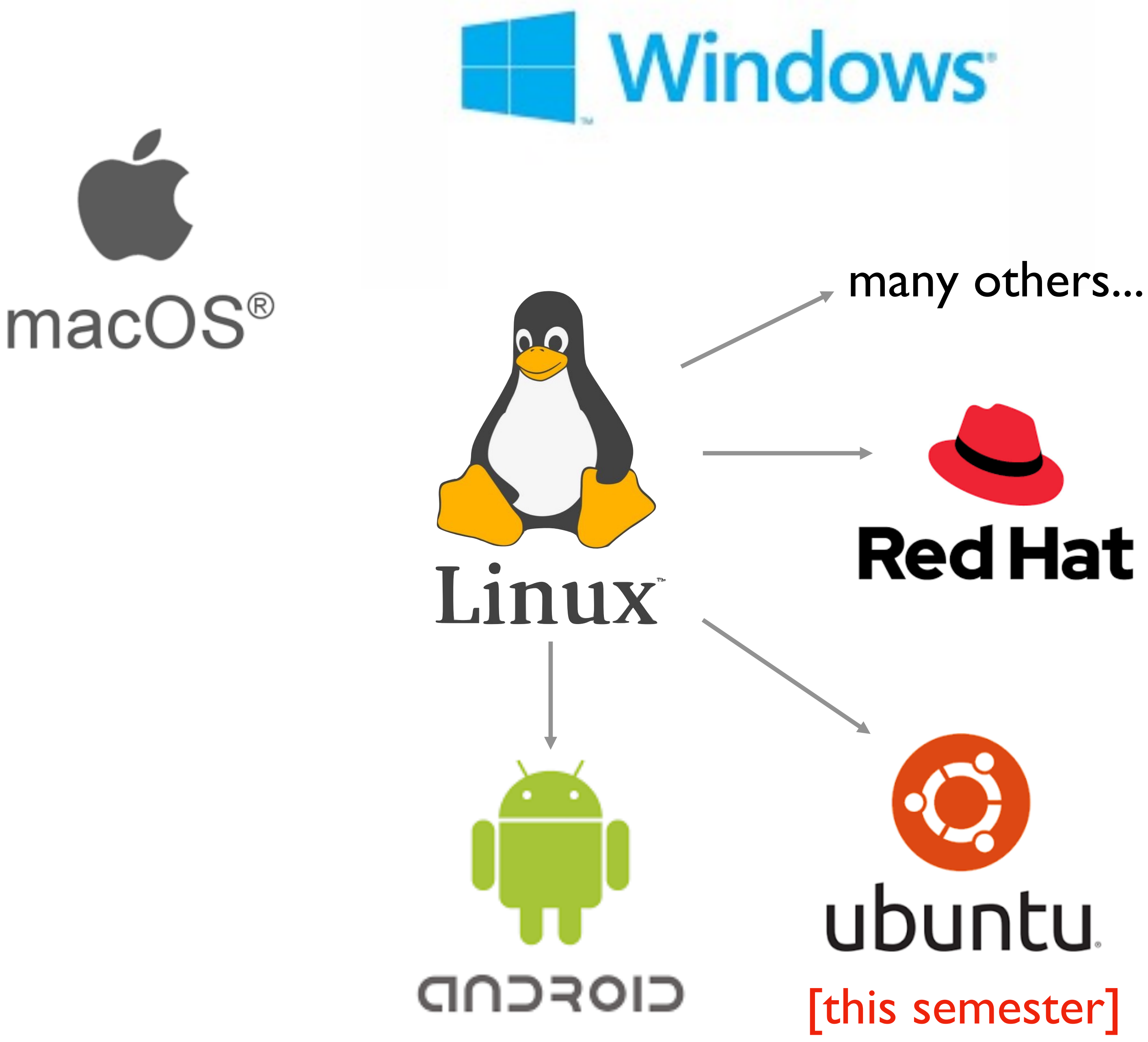
Interpreters (such as python.exe) make it easier to run the same code on different machines

Discuss: *if all CPUs had the instruction set, would we still need a Python interpreter?*

Big question: *will my program run on someone else's computer?* (not necessarily written in Python)

Things to match:

1. Hardware
2. Operating System
3. Dependencies



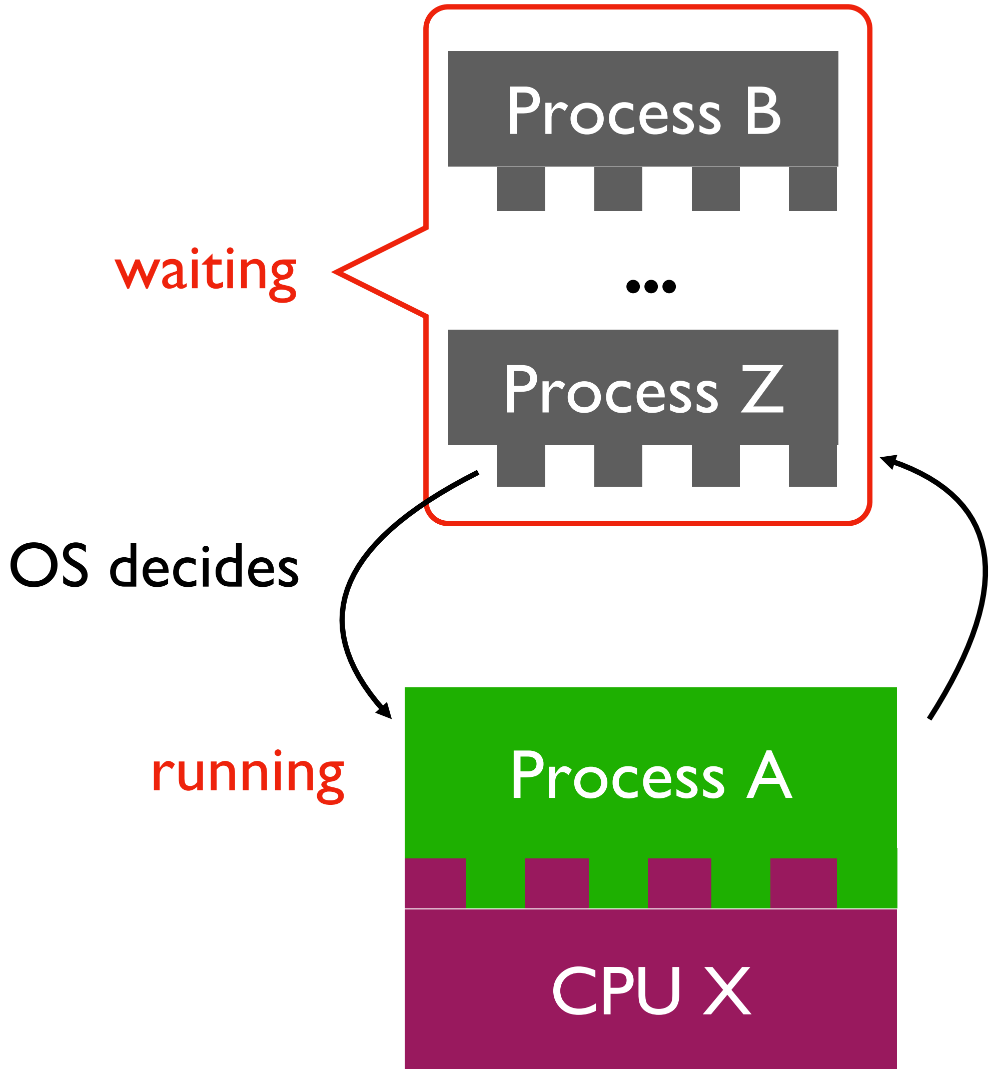
many others...

[this semester]

OS jobs: Allocate and Abstract Resources

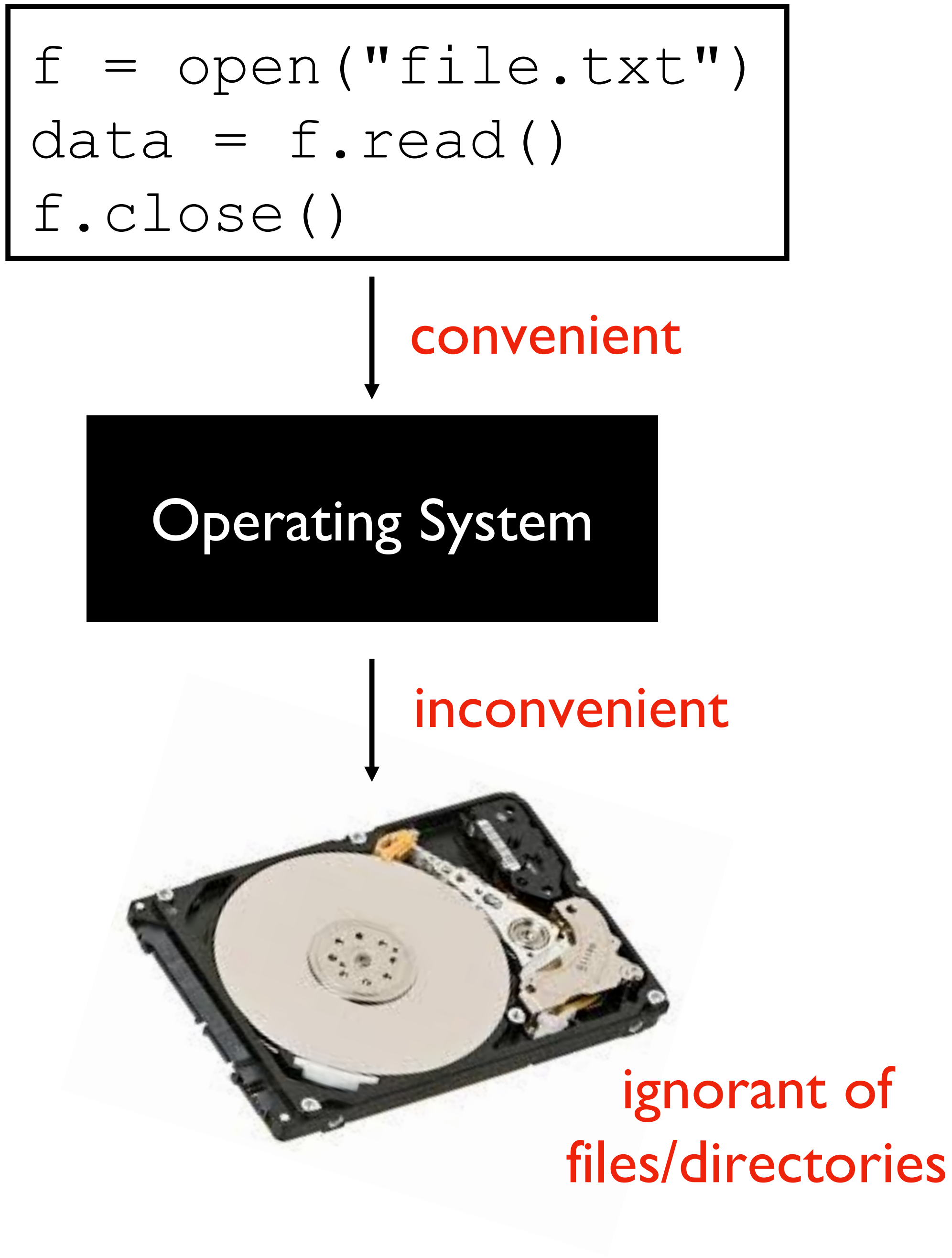
[like CPU, hard drive, etc]

1 Allocation



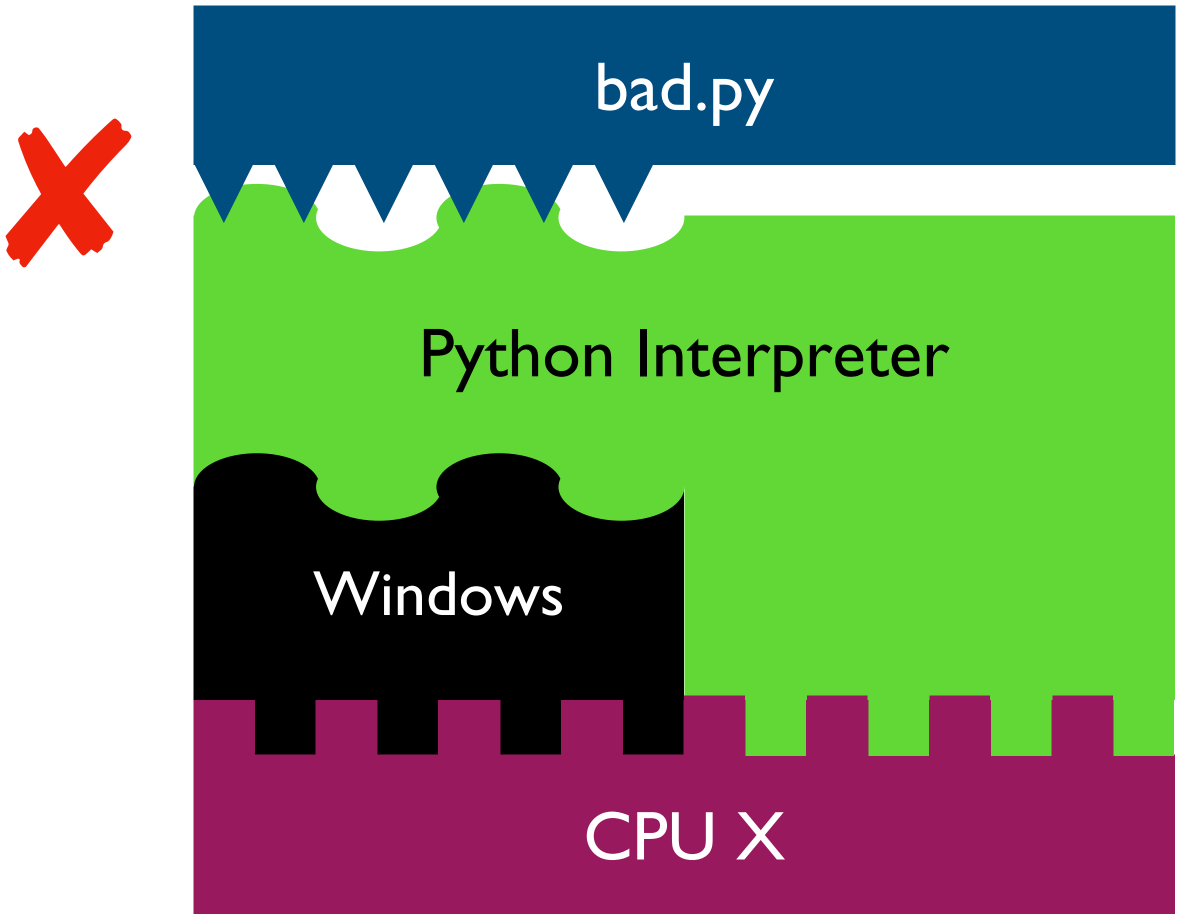
only one process can run on CPU at a time
(or a few things if the CPU has multiple "cores")

2 Abstraction



```
f = open("file.txt")
data = f.read()
f.close()
```

Harder to reproduce on different OS...

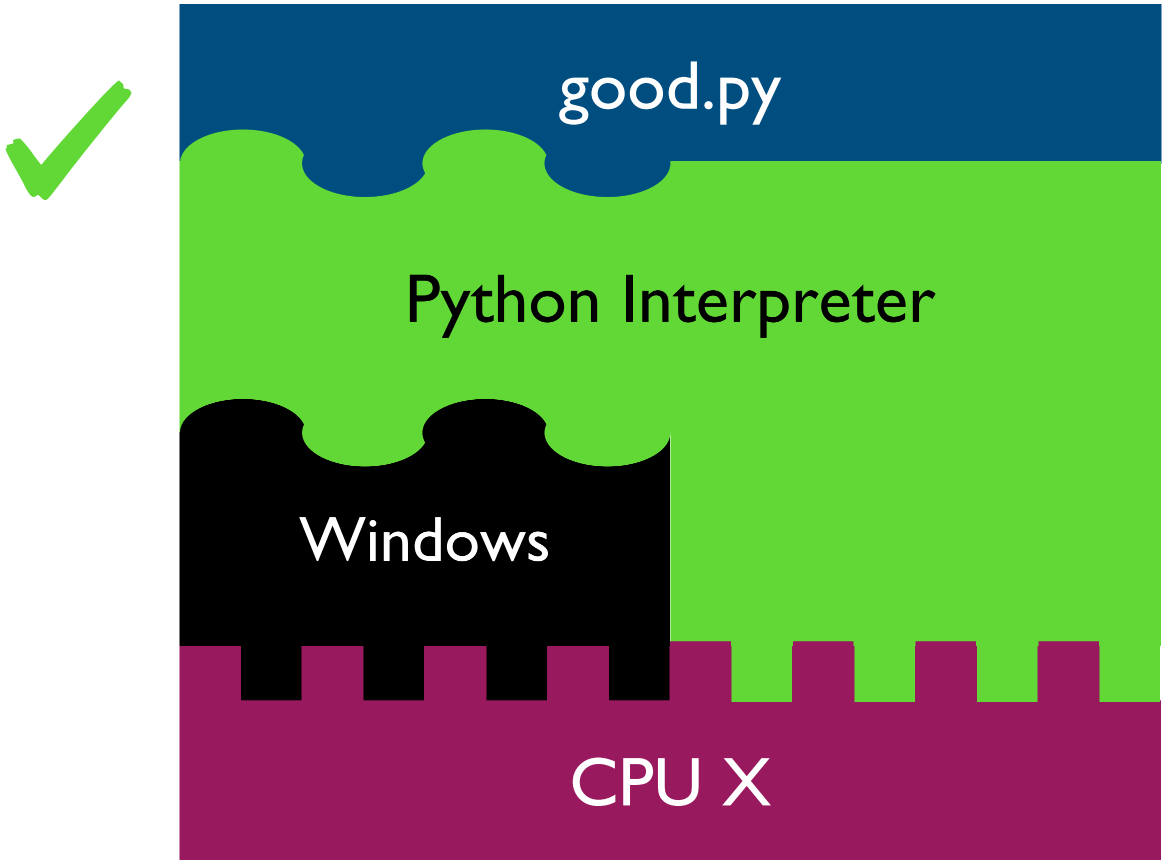


```
f = open("/data/file.txt")
...
```

The Python interpreter mostly lets you
[Python Programmer] ignore the CPU you run on.

But you still need to work a bit to "fit" the code to the OS.

Harder to reproduce on different OS...

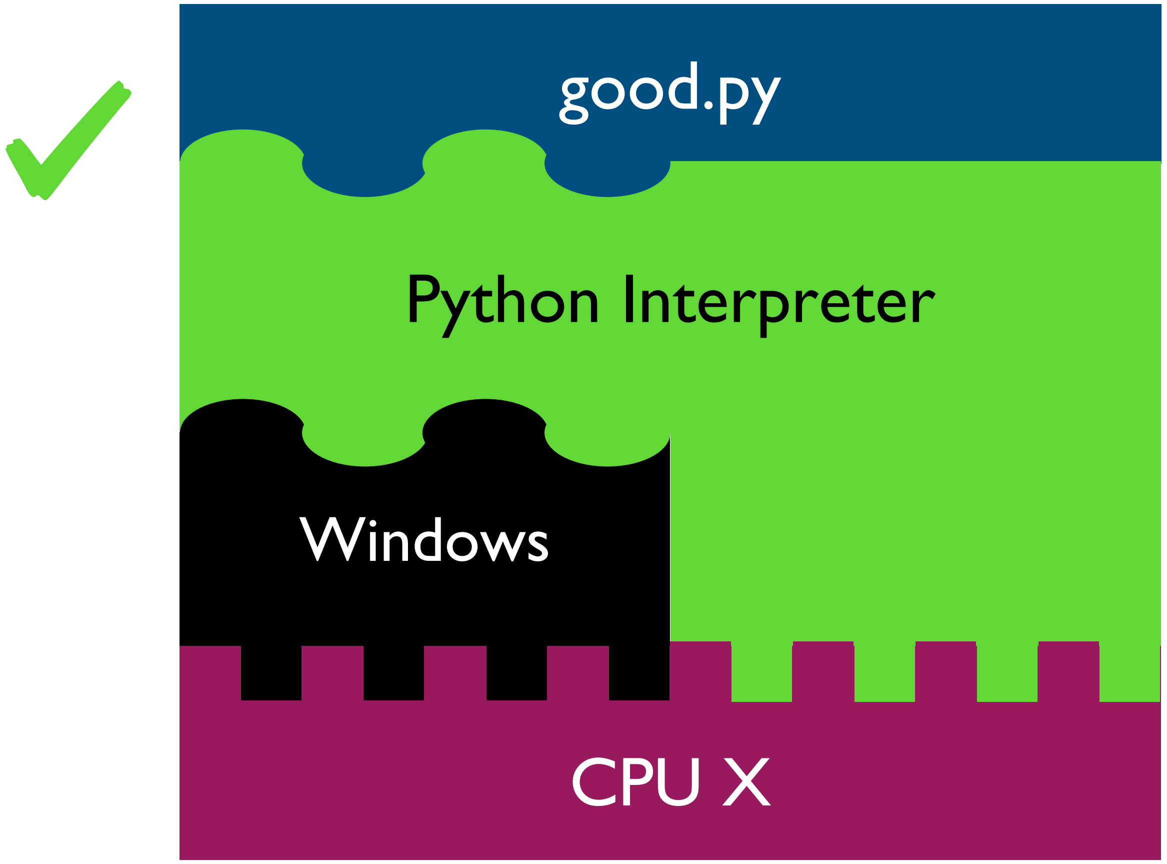


```
f = open("c:\data\file.txt")
...
```

The Python interpreter mostly lets you
[Python Programmer] ignore the CPU you run on.

But you still need to work a bit to "fit" the code to the OS.

Harder to reproduce on different OS...



# solution 1:

```
f = open(os.path.join("data", "file.txt"))
...
```

# solution 2:

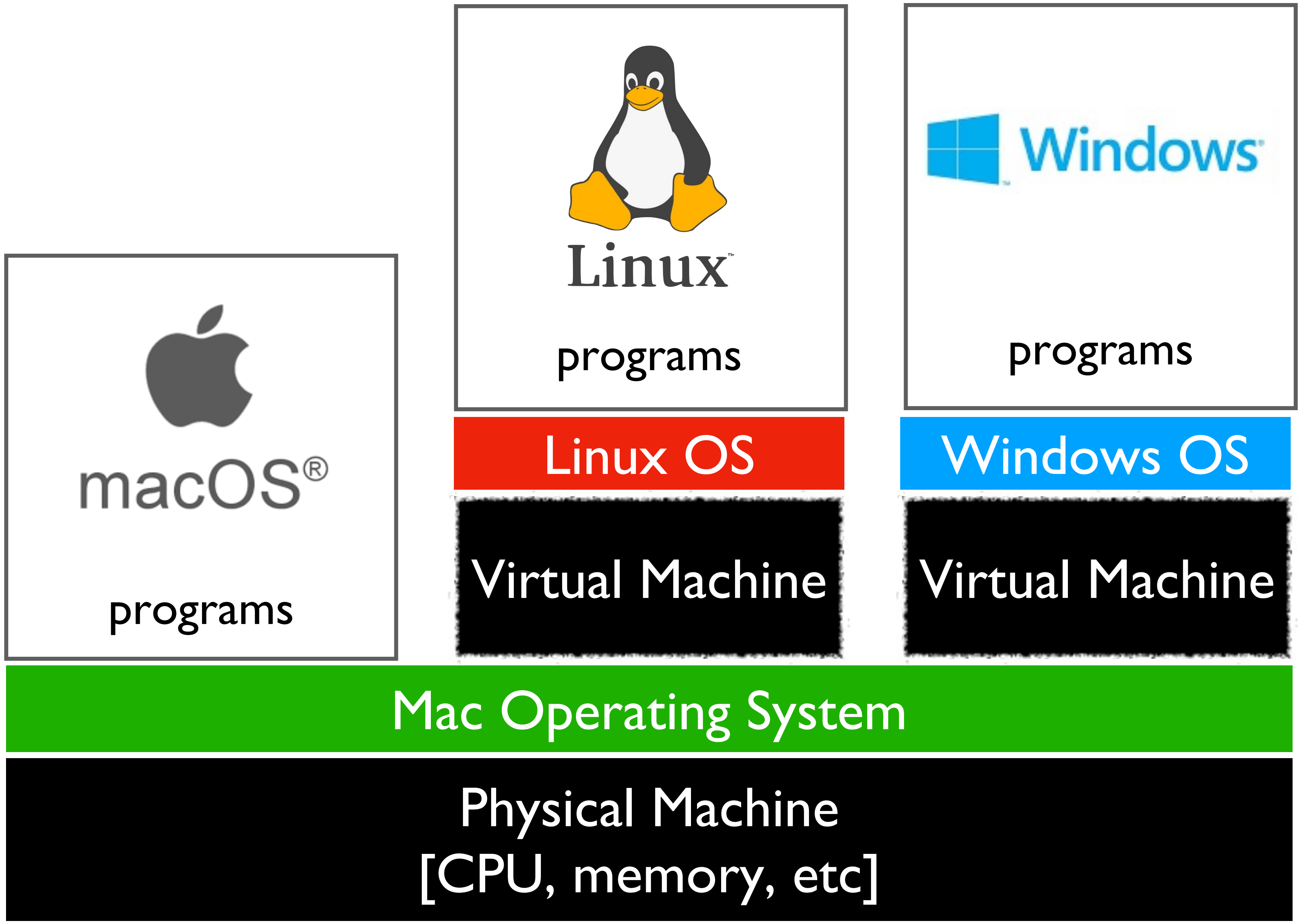
tell anybody reproducing your results to use the same OS!

tradeoffs?

The Python interpreter mostly lets you [Python Programmer] ignore the CPU you run on.

But you still need to work a bit to "fit" the code to the OS.

VMs (Virtual Machines)



programs

programs

programs

Linux OS

Windows OS

Virtual Machine

Virtual Machine

Mac Operating System

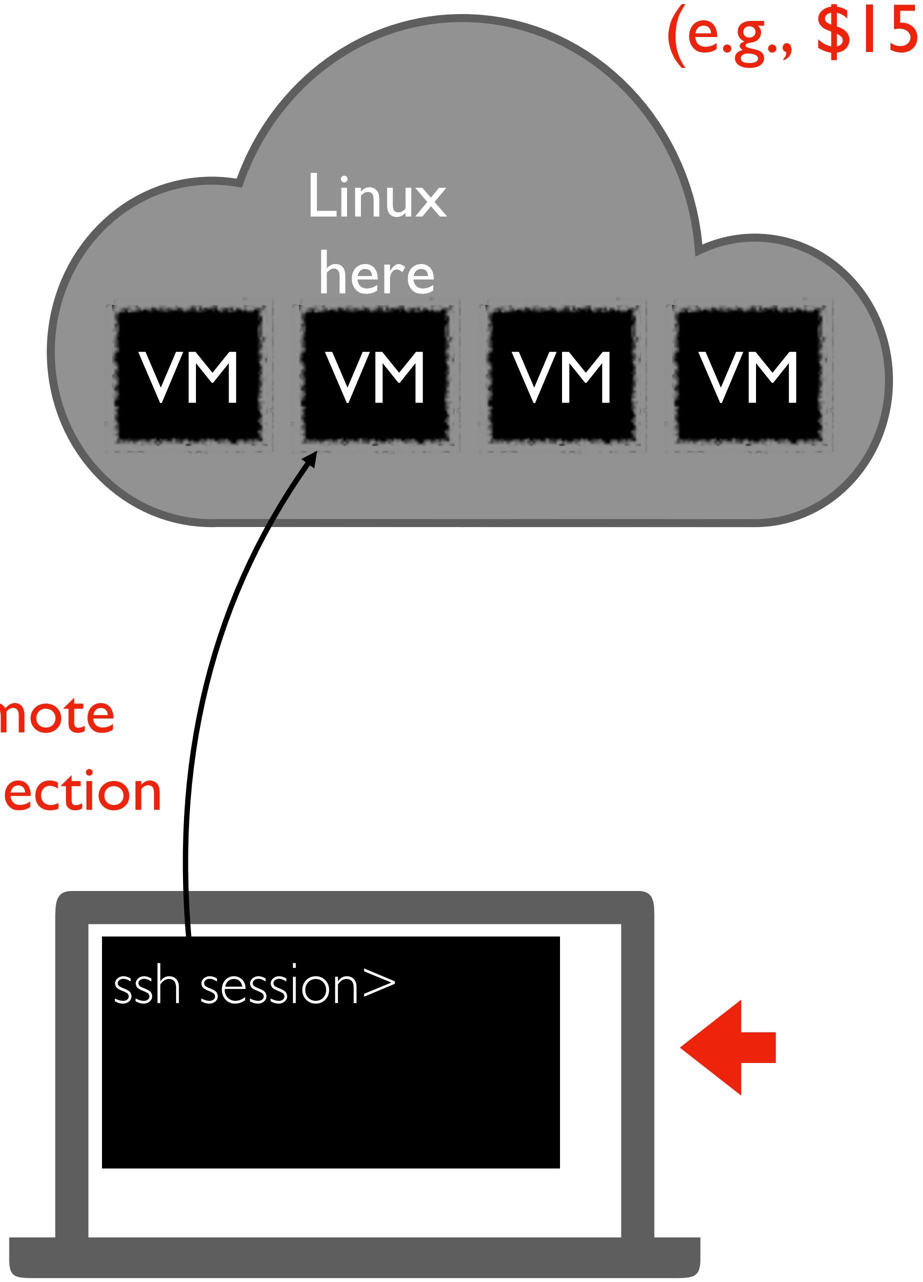
Physical Machine
[CPU, memory, etc]

popular virtual machine software

With the right virtual machines created and operating systems installed, you could run programs for Mac, Linux, and Windows -- at the same time without rebooting!

The Cloud

cloud providers let you rent VMs in the cloud on hourly basis (e.g., $15 / month)



Linux here

VM VM VM VM

remote connection

ssh session>

Windows, Mac, whatever

```
ssh user@best-linux.cs.wisc.edu
```

run in PowerShell/bash to access CS lab

popular cloud providers

amazon web services™

Microsoft Azure

Google Cloud Platform

we'll use GCP virtual machines this semester [setup in lab]

https://docs.microsoft.com/en-us/windows-server/administration/openssh/openssh_install_firstuse

Lecture Recap: Reproducibility

Big question: *will my program run on someone else's computer?*

Things to match:

1 Hardware ← a program must fit the CPU; `python.exe` will do this, so `program.py` won't have to

2 Operating System ← we'll use Ubuntu Linux on virtual machines in the cloud

3 Dependencies ← today: versioning

Recap of 15 new terms

reproducibility: others can run our analysis code and get same results

process: a running program

byte: integer between 0 and 255

address space: a big "list" of bytes, per process, for all state

address: index in the big list

encoding: pairing of ~~letters~~ characters with numeric codes

CPU: chip that executes instructions, tracks position in code

instruction set: pairing of CPU instructions/ops with numeric codes

operating system: software that allocates+abstracts resources

resource: time on CPU, space in memory, space on SSD, etc

allocation: the giving of a resource to a process

abstraction: hiding inconvenient details with something easier to use

virtual machine: "fake" machine running on ~~real~~ physical machine
allows us to run additional operating systems

cloud: place where you can rent virtual machines and other services

ssh: secure shell -- tool that lets you remotely access another machine

[320] Version Control (git)

Yiyin Shen

Reproducibility

Big question: *will my program run on someone else's computer?*

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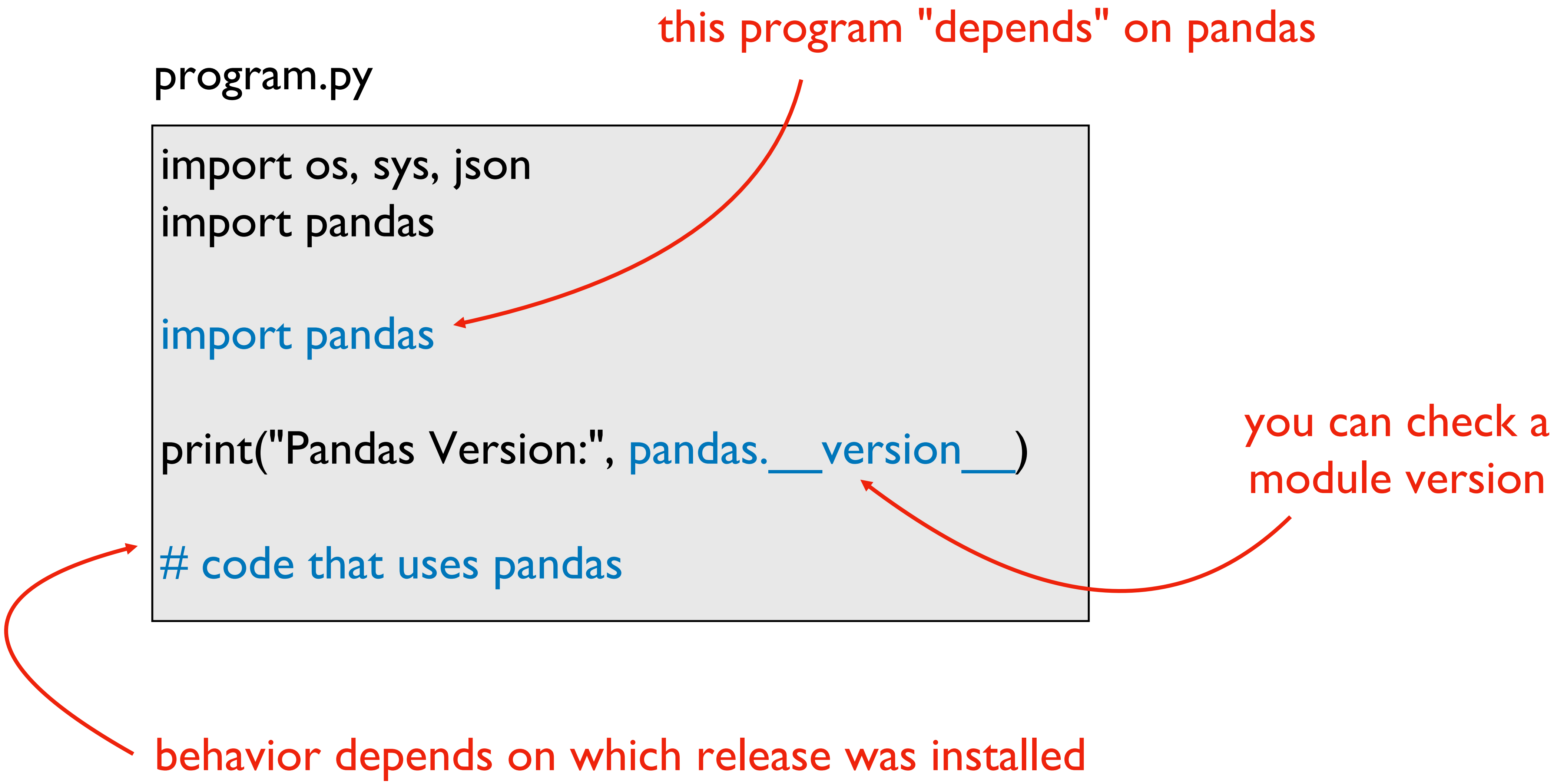
Dependency Versions



this program "depends" on pandas

program.py

```
import os, sys, json
import pandas

import pandas

print("Pandas Version:", pandas.__version__)

# code that uses pandas
```

you can check a module version

behavior depends on which release was installed

```
pip install pandas
```

or

```
pip install pandas==0.25.1
```

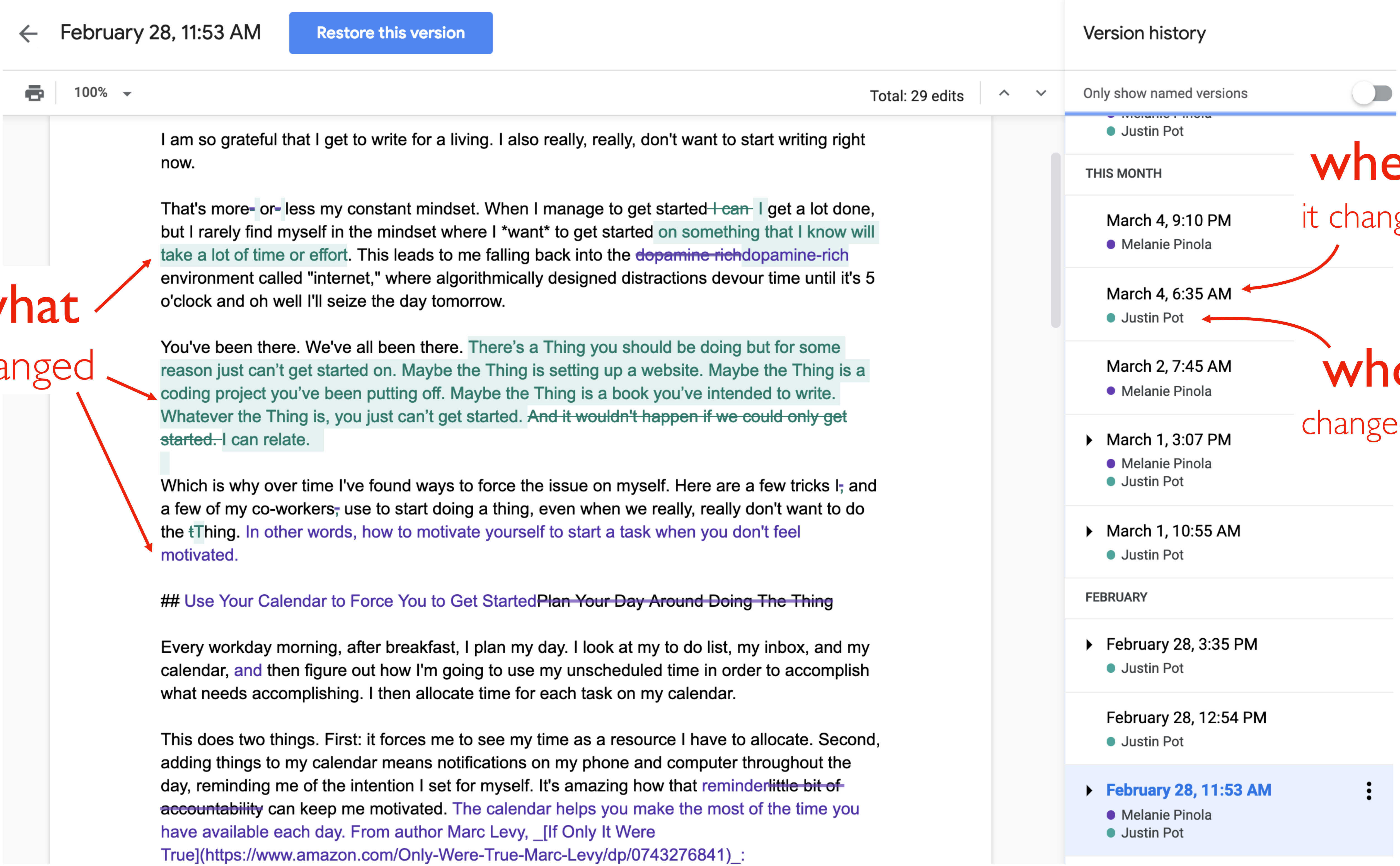
or

```
pip install pandas==0.24.0
```

or...

Versioning: motivation and basic concepts

Many tools auto-track history (e.g., Google Docs)



February 28, 11:53 AM

Total: 29 edits

I am so grateful that I get to write for a living. I also really, really, don't want to start writing right now.

That's more~~-~~ or~~-~~ less my constant mindset. When I manage to get started~~ I can ~~ I get a lot done, but I rarely find myself in the mindset where I *want* to get started on something that I know will take a lot of time or effort. This leads to me falling back into the ~~dopamine-rich~~dopamine-rich environment called "internet," where algorithmically designed distractions devour time until it's 5 o'clock and oh well I'll seize the day tomorrow.

You've been there. We've all been there. There's a Thing you should be doing but for some reason just can't get started on. Maybe the Thing is setting up a website. Maybe the Thing is a coding project you've been putting off. Maybe the Thing is a book you've intended to write. Whatever the Thing is, you just can't get started. ~~And it wouldn't happen if we could only get started.~~ I can relate.

Which is why over time I've found ways to force the issue on myself. Here are a few tricks I~~,~~ and a few of my co-workers~~,~~ use to start doing a thing, even when we really, really don't want to do the ~~t~~Thing. In other words, how to motivate yourself to start a task when you don't feel motivated.

Use Your Calendar to Force You to Get Started~~Plan Your Day Around Doing The Thing~~

Every workday morning, after breakfast, I plan my day. I look at my to do list, my inbox, and my calendar, and then figure out how I'm going to use my unscheduled time in order to accomplish what needs accomplishing. I then allocate time for each task on my calendar.

This does two things. First: it forces me to see my time as a resource I have to allocate. Second, adding things to my calendar means notifications on my phone and computer throughout the day, reminding me of the intention I set for myself. It's amazing how that reminder~~little bit of accountability~~ can keep me motivated. The calendar helps you make the most of the time you have available each day. From author Marc Levy, _[If Only It Were True](https://www.amazon.com/Only-Were-True-Marc-Levy/dp/0743276841)_:

Version history

Only show named versions

● Melanie Pinola
● Justin Pot

THIS MONTH

March 4, 9:10 PM
● Melanie Pinola

March 4, 6:35 AM
● Justin Pot

March 2, 7:45 AM
● Melanie Pinola

March 1, 3:07 PM
● Melanie Pinola
● Justin Pot

March 1, 10:55 AM
● Justin Pot

FEBRUARY

February 28, 3:35 PM
● Justin Pot

February 28, 12:54 PM
● Justin Pot

February 28, 11:53 AM
● Melanie Pinola
● Justin Pot

what changed

when it changed

who changed it

https://zapier.com/apps/google-docs/tutorials/google-docs-revision-history

Version Control Systems (VCS)

Useful for many kinds of projects

- code, papers, websites, etc
- manages all files for same project (maybe thousands) in a repository

Explicit snapshots/checkpoints, called *commits*

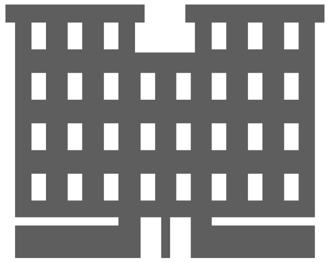
- users **manually** run commands to preserve good versions

Explicit commit messages

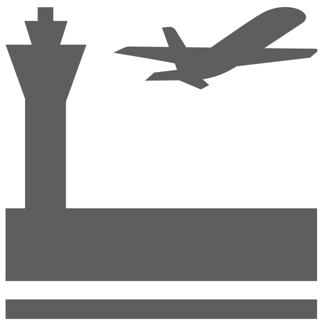
- who, what, when, **why**

Work can *branch* out and be *merged* back

- people can work offline
- can get feedback before merging
- humans need to resolve ***conflicts*** when versions being merged are too different



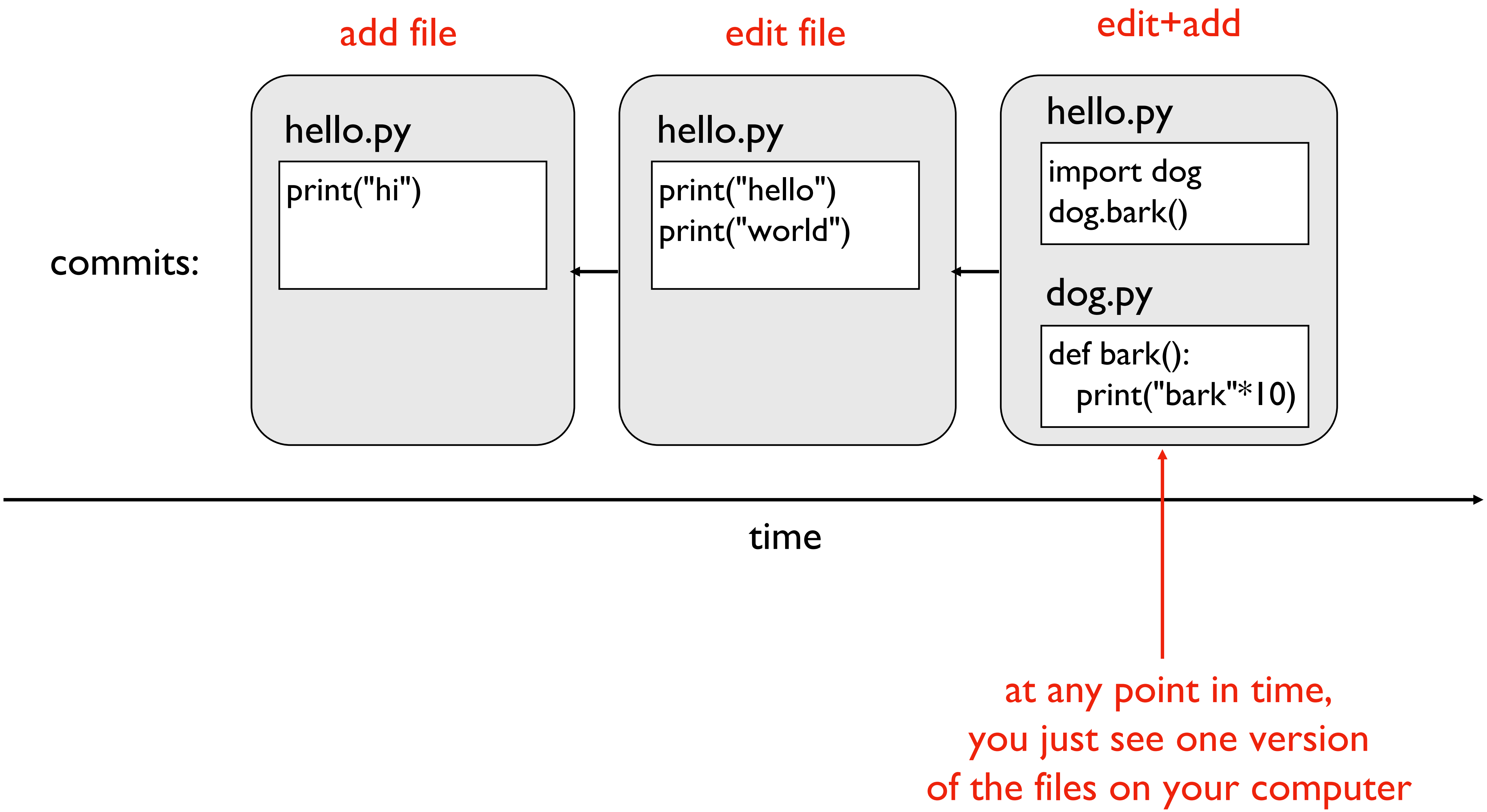
partner A working on `hw.py` at school



partner B also working on `hw.py`, without wifi

what happens when the plane lands?

Example



commits:

add file

hello.py

```
print("hi")
```

edit file

hello.py

```
print("hello")
print("world")
```

edit+add

hello.py

```
import dog
dog.bark()
```

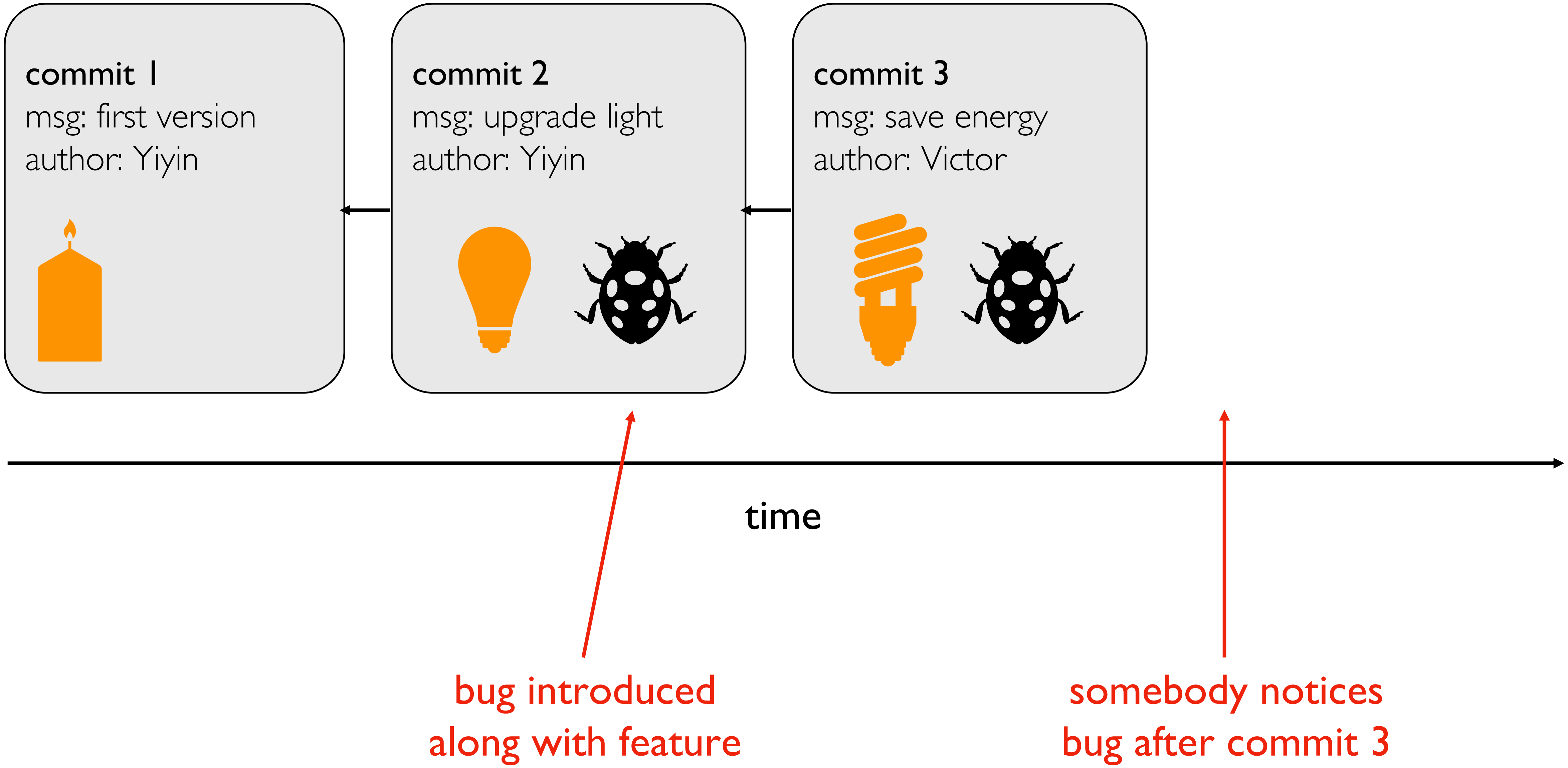
dog.py

```
def bark():
   print("bark"*10)
```

time

at any point in time,
you just see one version
of the files on your computer

Use case 1: troubleshooting discovered bug



commit 1
msg: first version
author: Yiyin

commit 2
msg: upgrade light
author: Yiyin

commit 3
msg: save energy
author: Victor

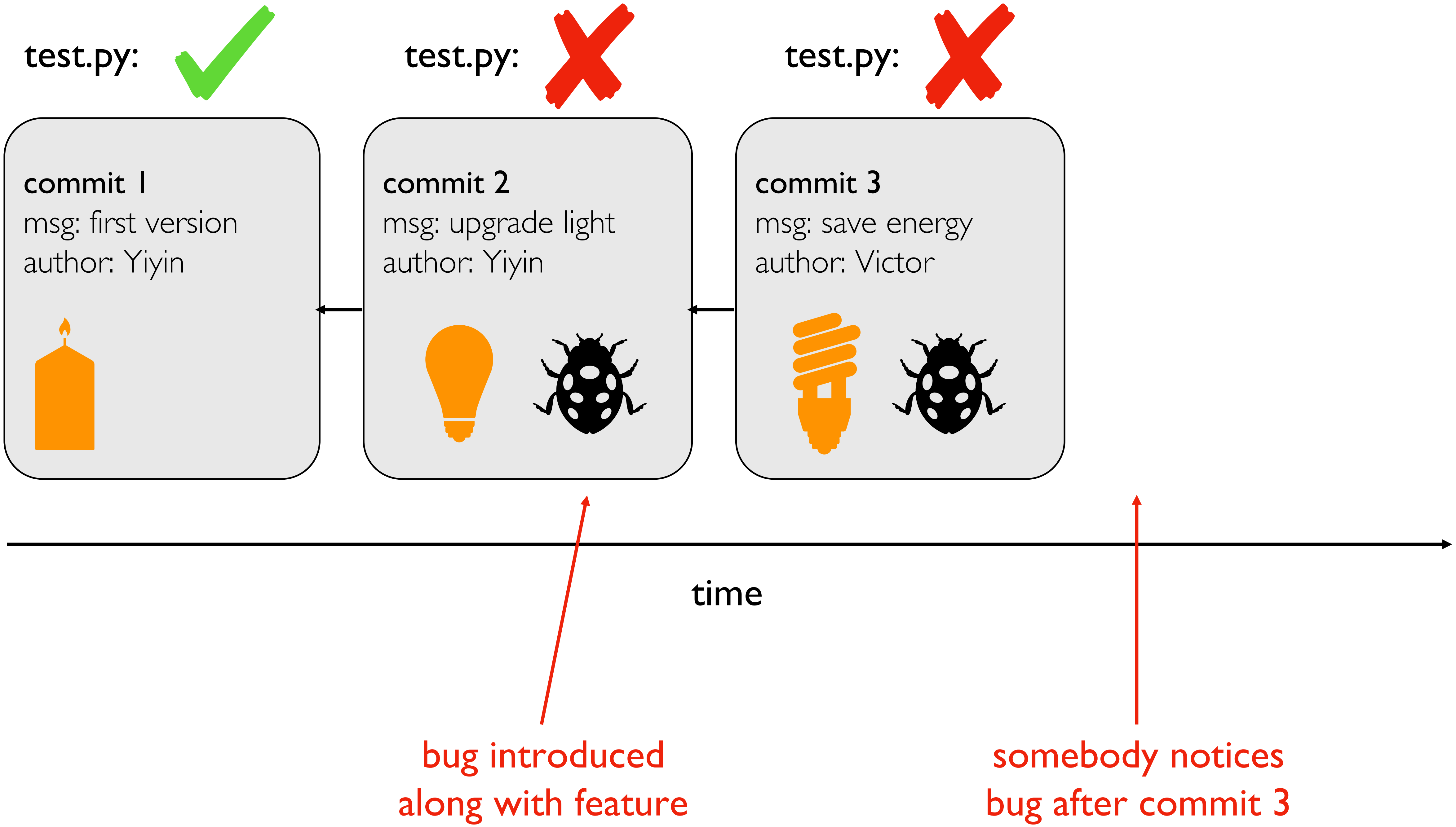
time

bug introduced
along with feature

somebody notices
bug after commit 3

who will get blamed?

Use case 1: troubleshooting discovered bug



test.py: ✓

commit 1
msg: first version
author: Yiyin

test.py: ✗

commit 2
msg: upgrade light
author: Yiyin

test.py: ✗

commit 3
msg: save energy
author: Victor

time

bug introduced
along with feature

somebody notices
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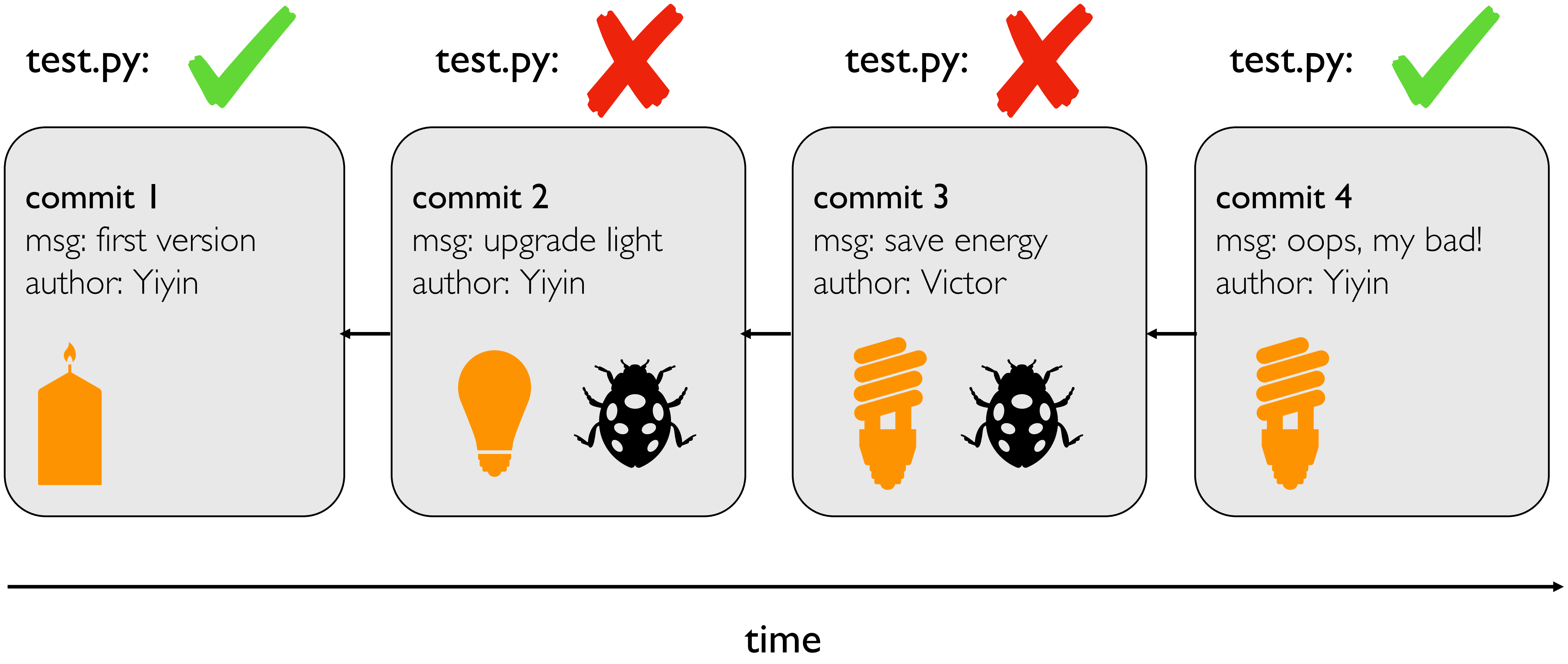
Use case 1: troubleshooting discovered bug



test.py: ✓

commit 1
msg: first version
author: Yiyin

test.py: ✗

commit 2
msg: upgrade light
author: Yiyin

test.py: ✗

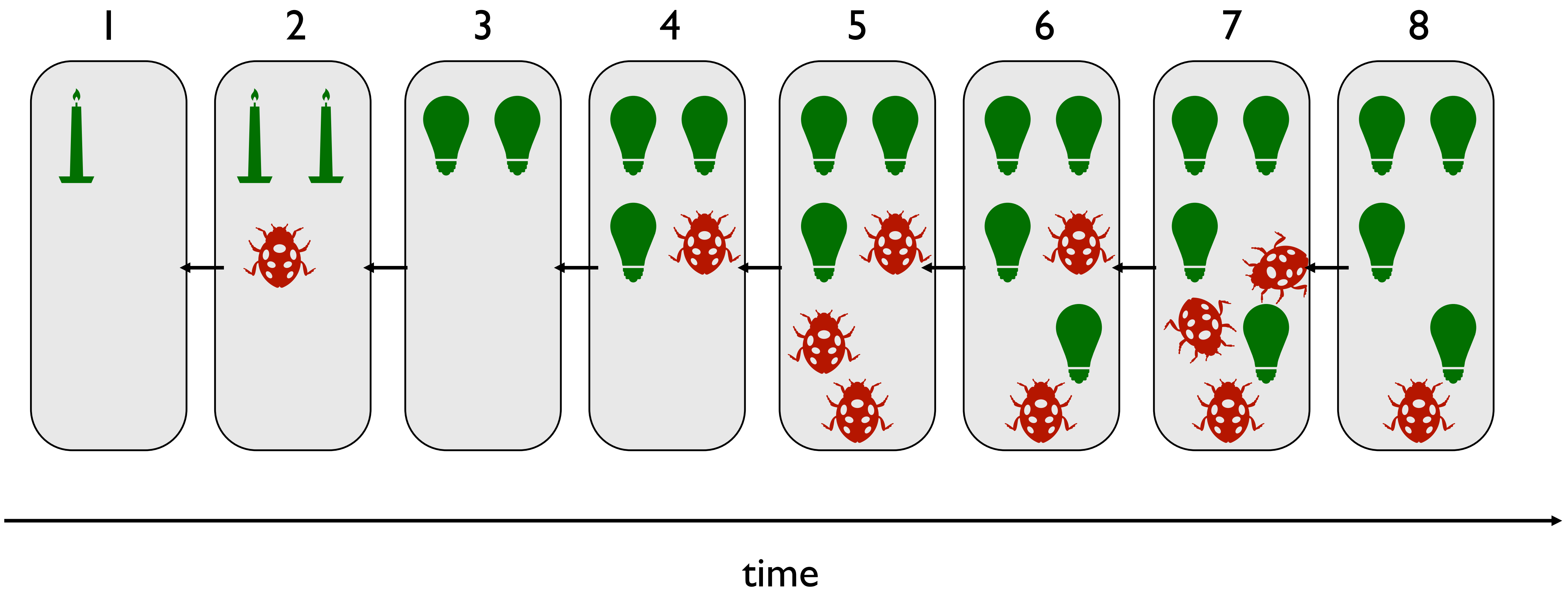
commit 3
msg: save energy
author: Victor

test.py: ✓

commit 4
msg: oops, my bad!
author: Yiyin

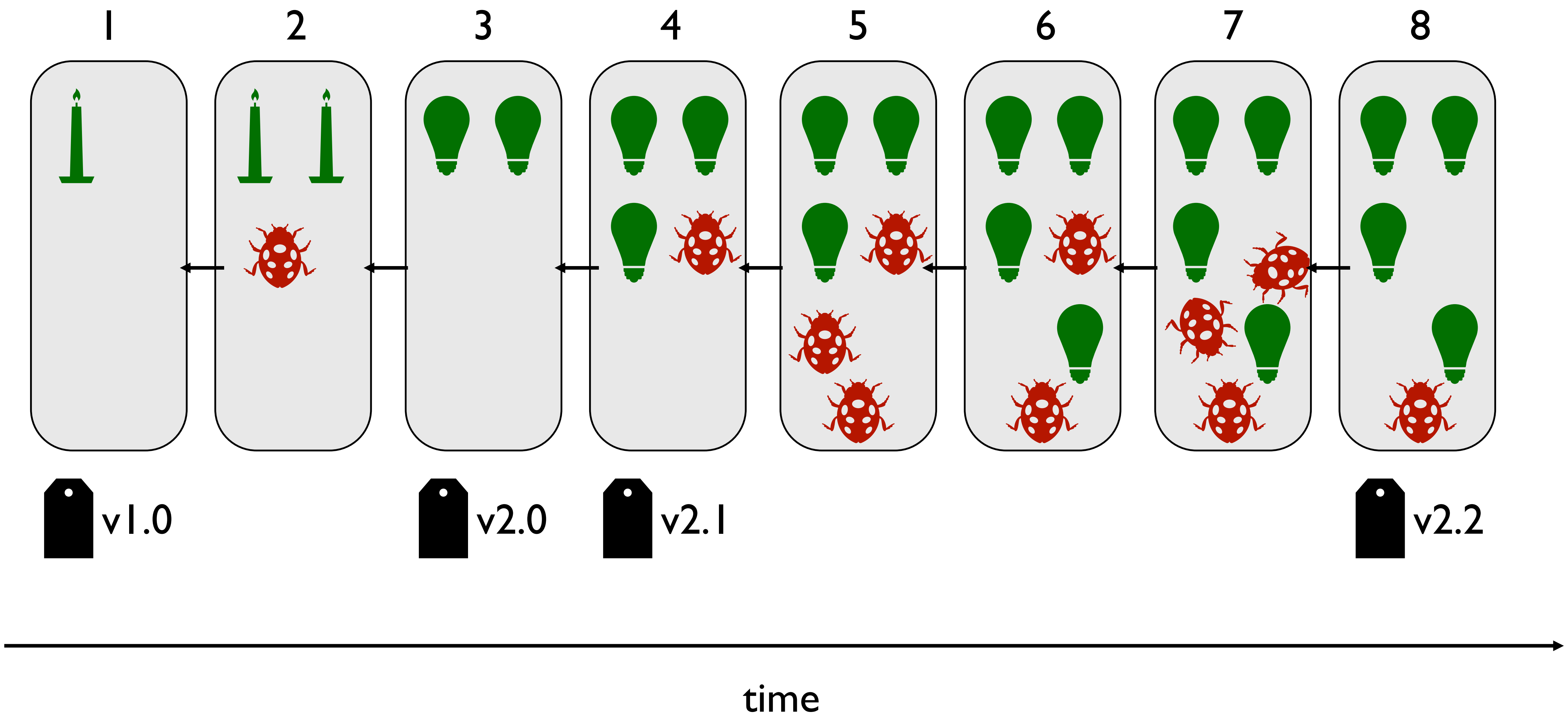
time

Use case 2: versioned releases



which version would you use?

Use case 2: versioned releases

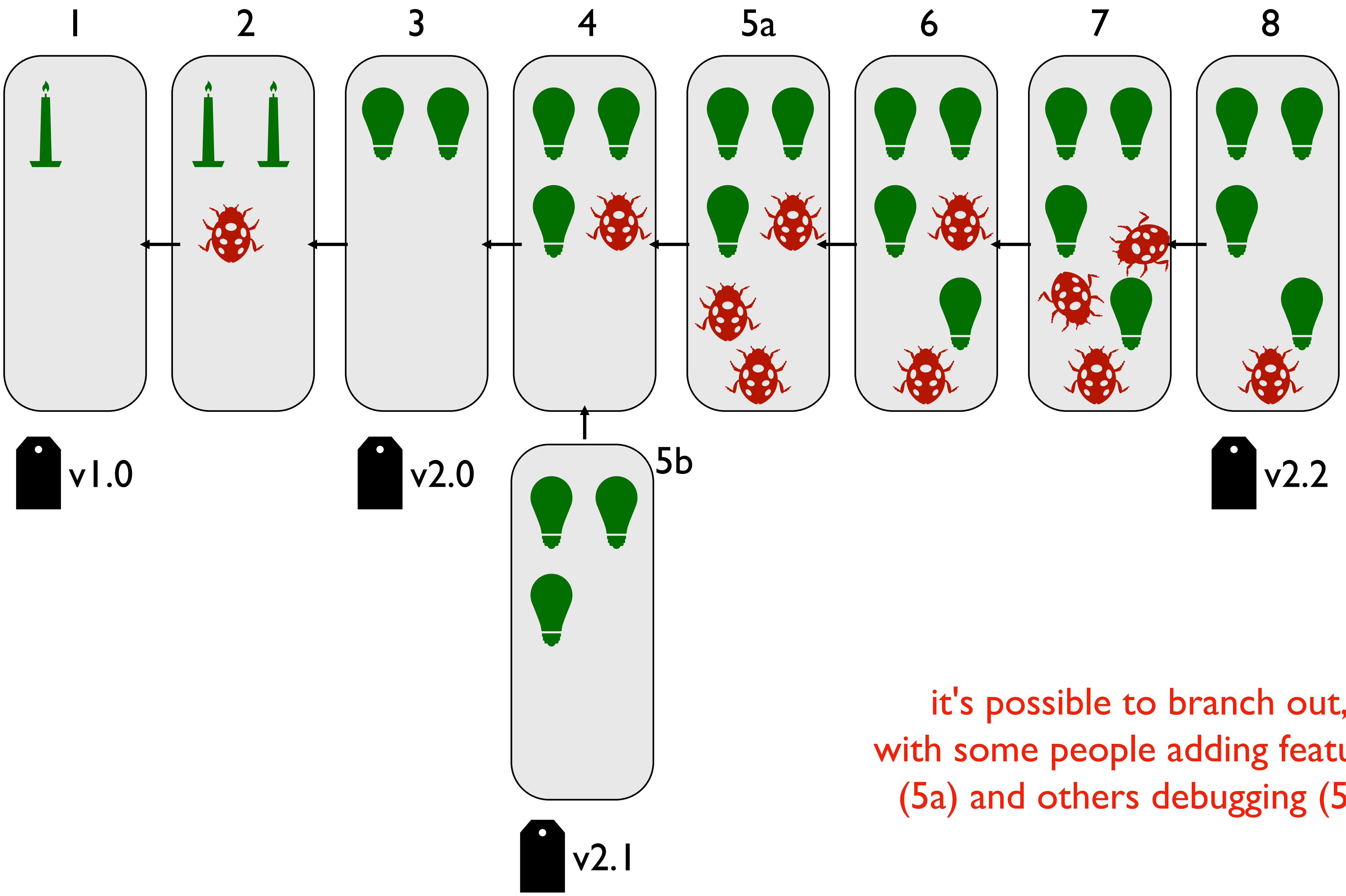


tag "good" commits to create releases

https://pypi.org/project/pandas/#history

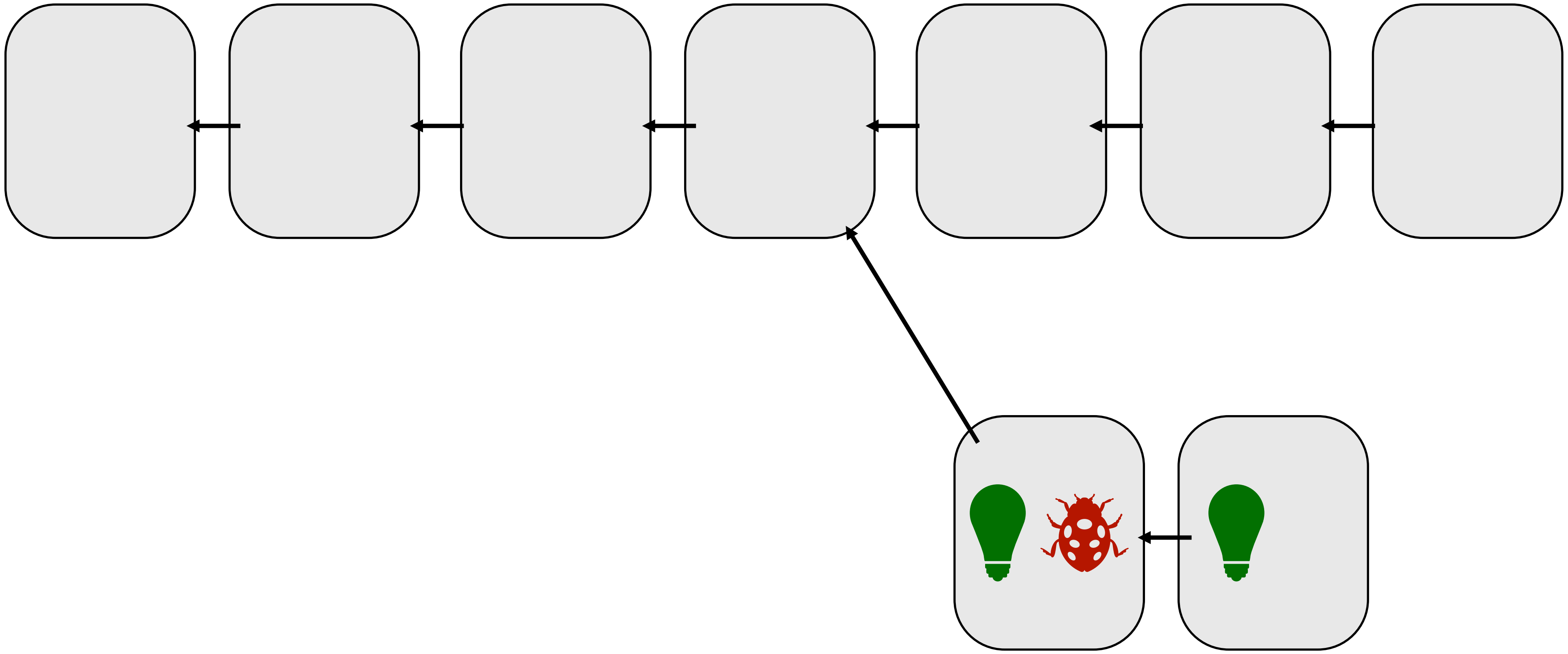
https://github.com/pandas-dev/pandas/releases

Use case 2: versioned releases



it's possible to branch out,
with some people adding features
(5a) and others debugging (5b)

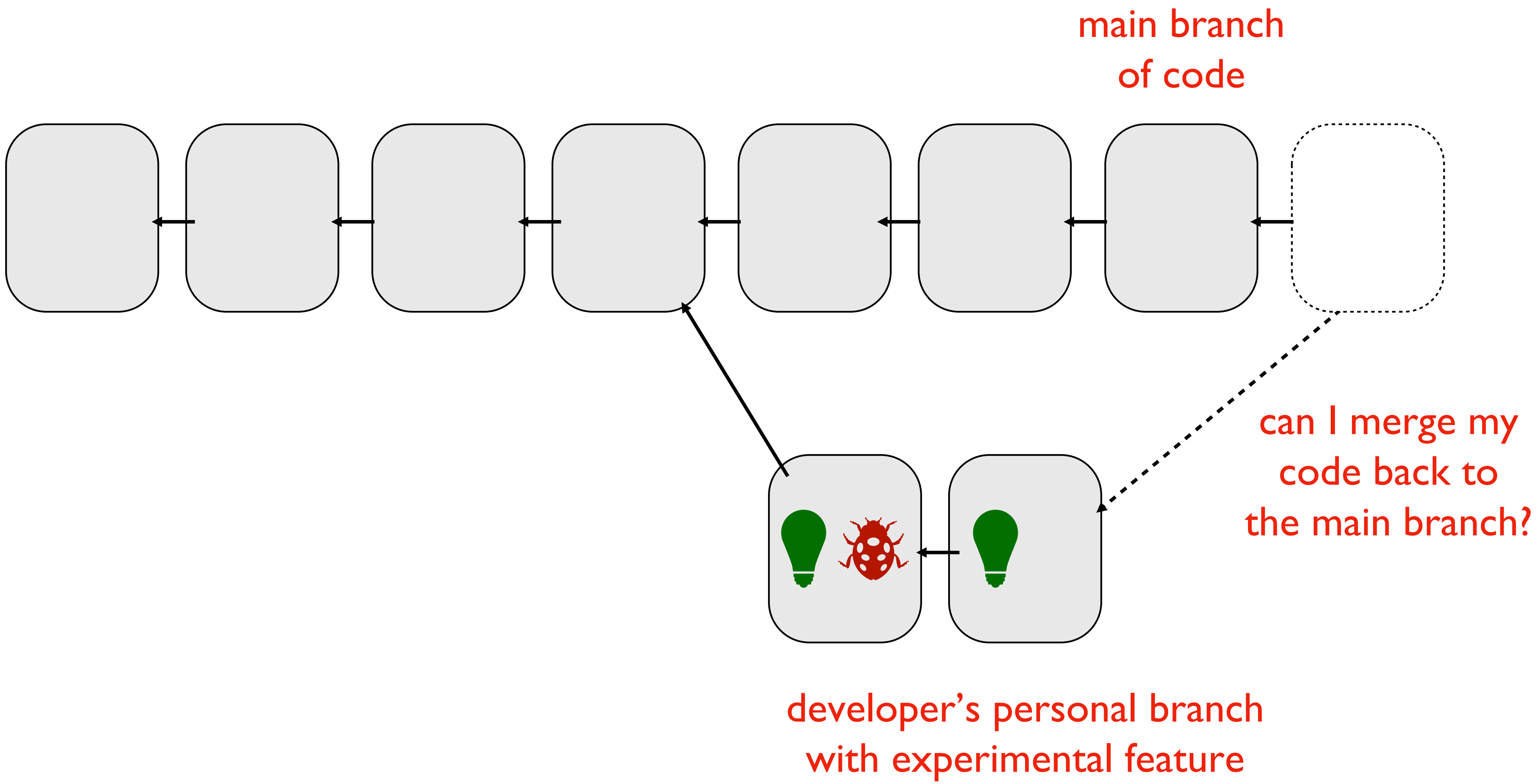
Use case 3: feedback



main branch
of code

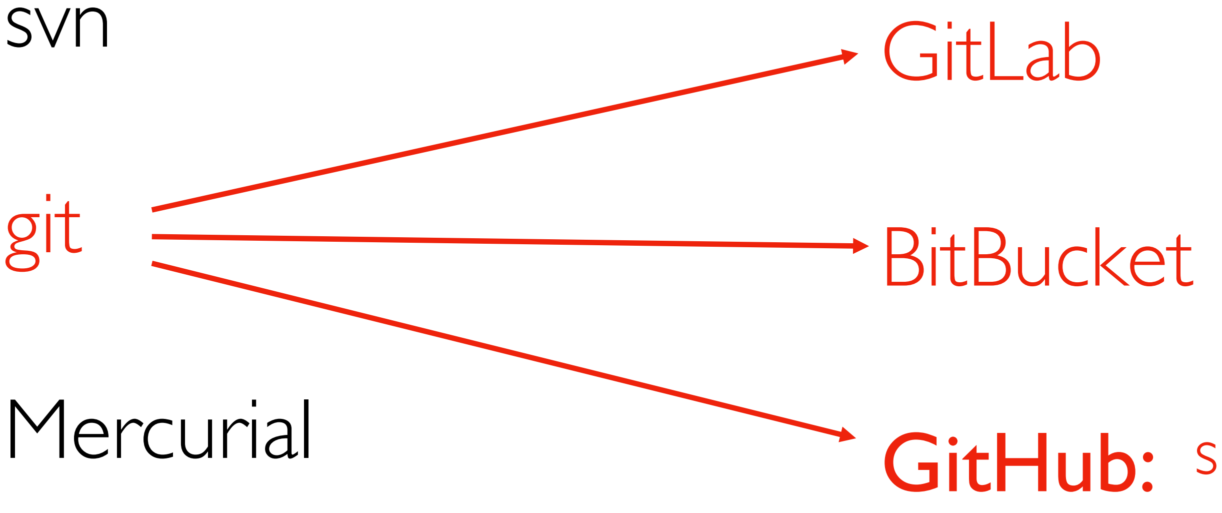
developer's personal branch
with experimental feature

Use case 3: feedback



git

Version Control System Tools



tools

svn

git

Mercurial

TeamFoundation

git providers

GitLab

BitBucket

GitHub: signup for a free account for next weeks lab

- **do** choose a name that won't embarrass you on a resume
- **do not** post course work

Linus Torvalds
developed git to manage
Linux as a
BitKeeper replacement

https://www.linuxjournal.com/content/25-years-later-interview-linus-torvalds

Git Demos

https://github.com/yiyins2/CS320-SU23/tree/main

Connect to VM:

- Mac: terminal; Windows: powershell
- ssh username@computer: connect to a VM via SSH

Shortcuts:

^D	exit connection
^C	terminate the current command
^R	search history

pwd	display current working directly
cd	go down a directory
cd ..	go up a directory
ls	list all files in the directory
cat	display the files

Git Demos

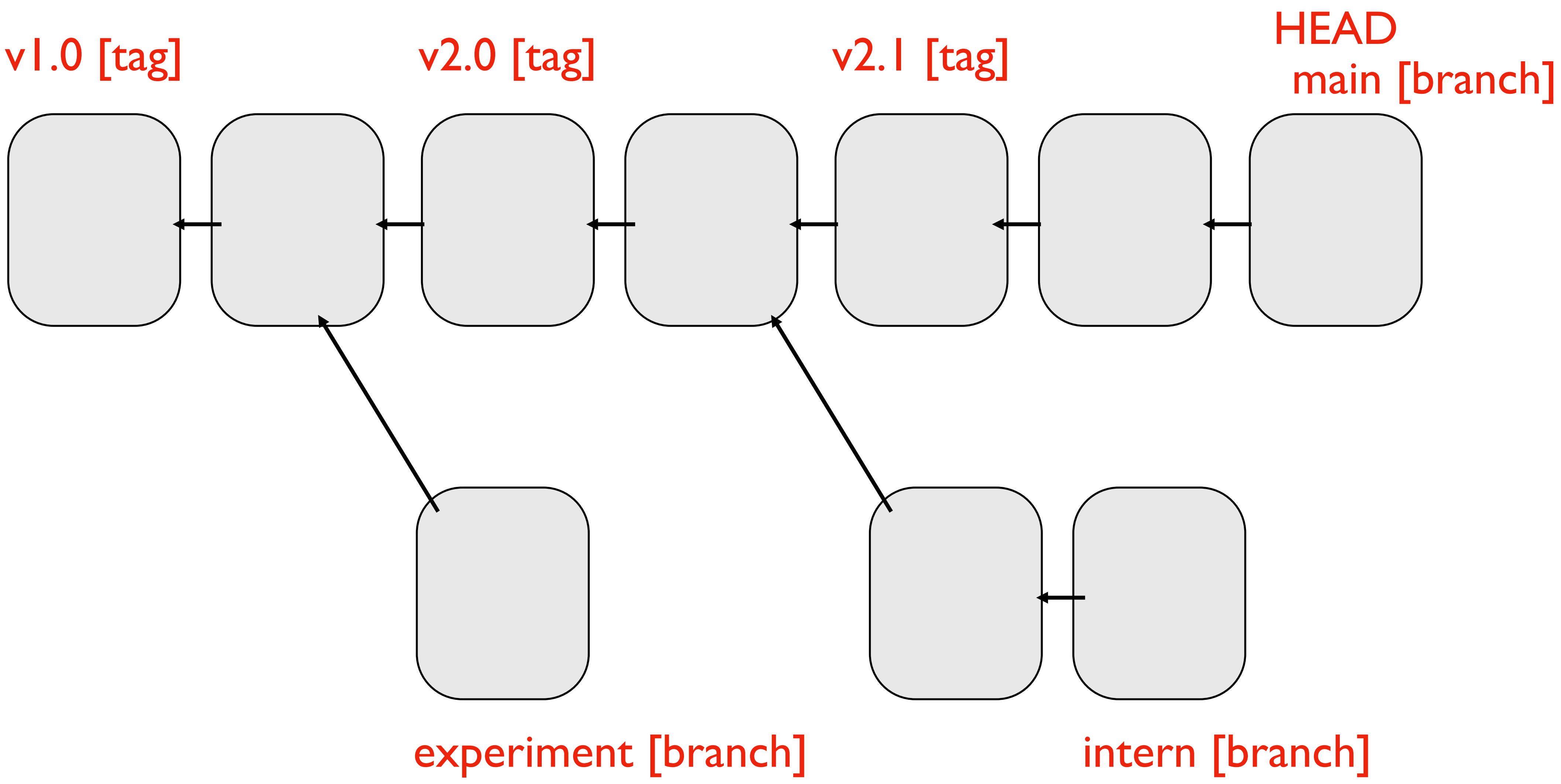
https://github.com/yiyins2/CS320-SU23/tree/main

Git Commands:

- git clone: retrieve an entire repository from a hosted location via URL
- git log: show all commits in the current branch's history
- git status: show modified files in working directory, staged for your next commit
- git pull: fetch and merge any commits from the tracking remote branch
- git add: add a file as it looks now to your next commit (stage)
- git commit: commit your staged content as a new commit snapshot
- git push: transmit local branch commits to the remote repository branch
- git branch: list your branches. a * will appear next to the currently active branch
- git checkout: switch to another branch and check it out into your working directory

HEAD, Branches, and Tags

Remembering commit numbers is a pain! Various kinds of labels can serve as easy-to-remember aliases



HEAD: wherever you currently are (only one of these)
tag: label tied to a specific commit number
branch: label tied to end of chain (moves upon new commits)