NOAA Modeling Fair
Python Session

– September 11, 2018 –

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NOAA NCEP EMC / IM Systems Group

Session Overview

- Talk 1: *Python: What it is and What it is Not.*
  - Sam Trahan
- Talk 2: *Reading Scientific Datasets in Python*
  - Todd Spindler
- Talk 3: *Graphical Diagnostic Tools*
  - Hyun-Sook Kim
- Talk 4: *Time Series Data Analysis in Python*
  - Deanna Spindler

What is Python and What is it *Not*?

- From python.org website. This is half true:

  Python is an interpreted, object-oriented, high-level programming language with dynamic semantics. Its high-level built in data structures, combined with dynamic typing and dynamic binding, make it very attractive for Rapid Application Development, as well as for use as a scripting or glue language to connect existing components together... more text …

- This is half true:
  - Python is used for numerical computing, machine learning, data visualization, and much more. It is an ecosystem.

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“Python is”
“Language *XYZ* is”

- Formal, international, standards:
  - C++ – ISO/IEC 14882:2014
  - Fortran – ISO/IEC 1539-1:2010
  - C – ISO/IEC 9899:2018
- Proprietary standards:
  - Bash – GNU Project
  - Visual Basic – Microsoft
  - Matlab – MathWorks

~~“Python is”~~
Pythons are

- A list of recommendations (PEP) with a reference implementation (CPython) and no standard.
- Pythons are.
  - CPython – reference implementation from python.org
  - PyPy – Just In Time (JIT) compiler; usually faster than CPython
  - Jython – compiles to Java bytecode; usually faster than CPython
  - Cython – compiles Python to C; compatible with CPython
  - Numba – JIT compiler using LLVM, sits within CPython
  - IronPython – integrates Python into Visual Studio
- Similar language, different set of supported libraries.

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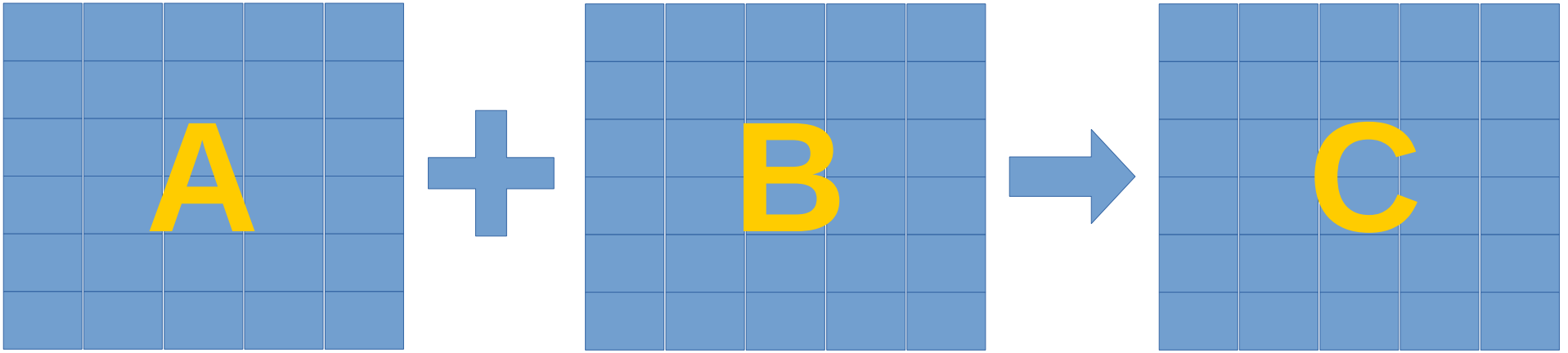
Languages: High vs Low
Low-Level Languages



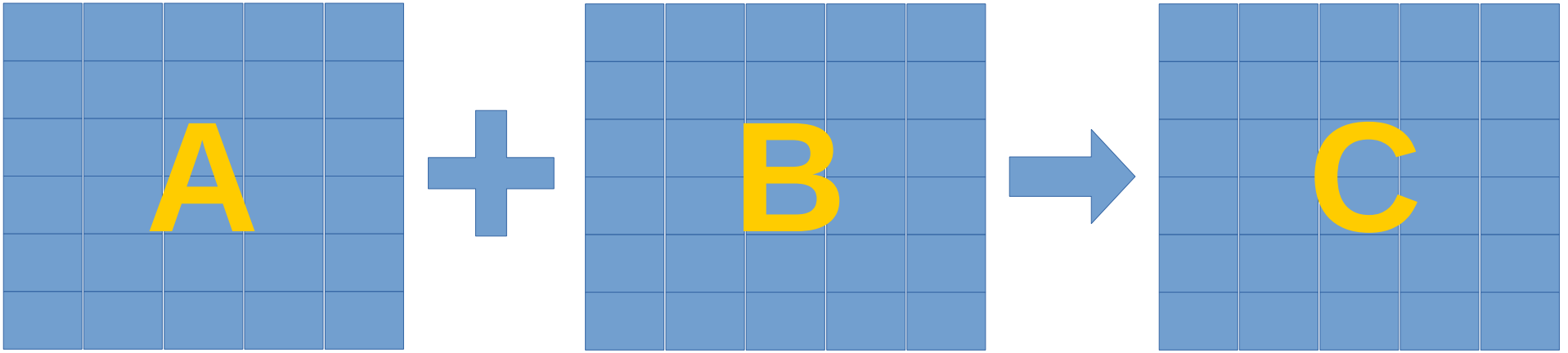
- Low-level Fortran

```
do j=1,m
  do i=1,n
    c(i,j) = a(i,j) + b(i,j)
  enddo
enddo
```

- Low-level C

```
for(j=0;j<m;j++)
  for(i=0;i<n;i++)
    c[j][i]=a[j][i]+b[j][i]
```

Languages: High vs Low
High-Level Languages



- High-level Fortran

  C = A + B

- High-level C++

  C = A + B;

- Python with numpy

  C = A + B

- High-level R

  C <- A + B

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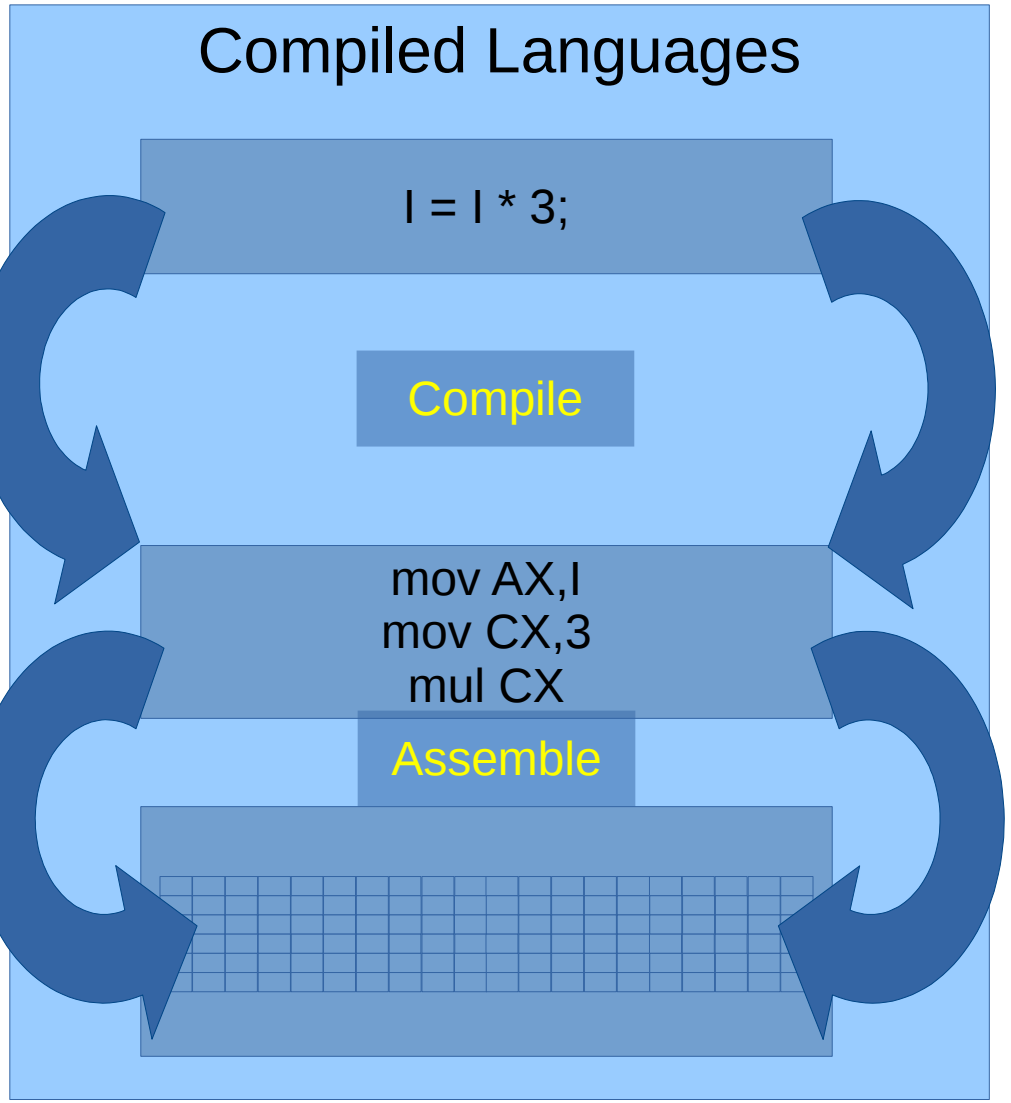
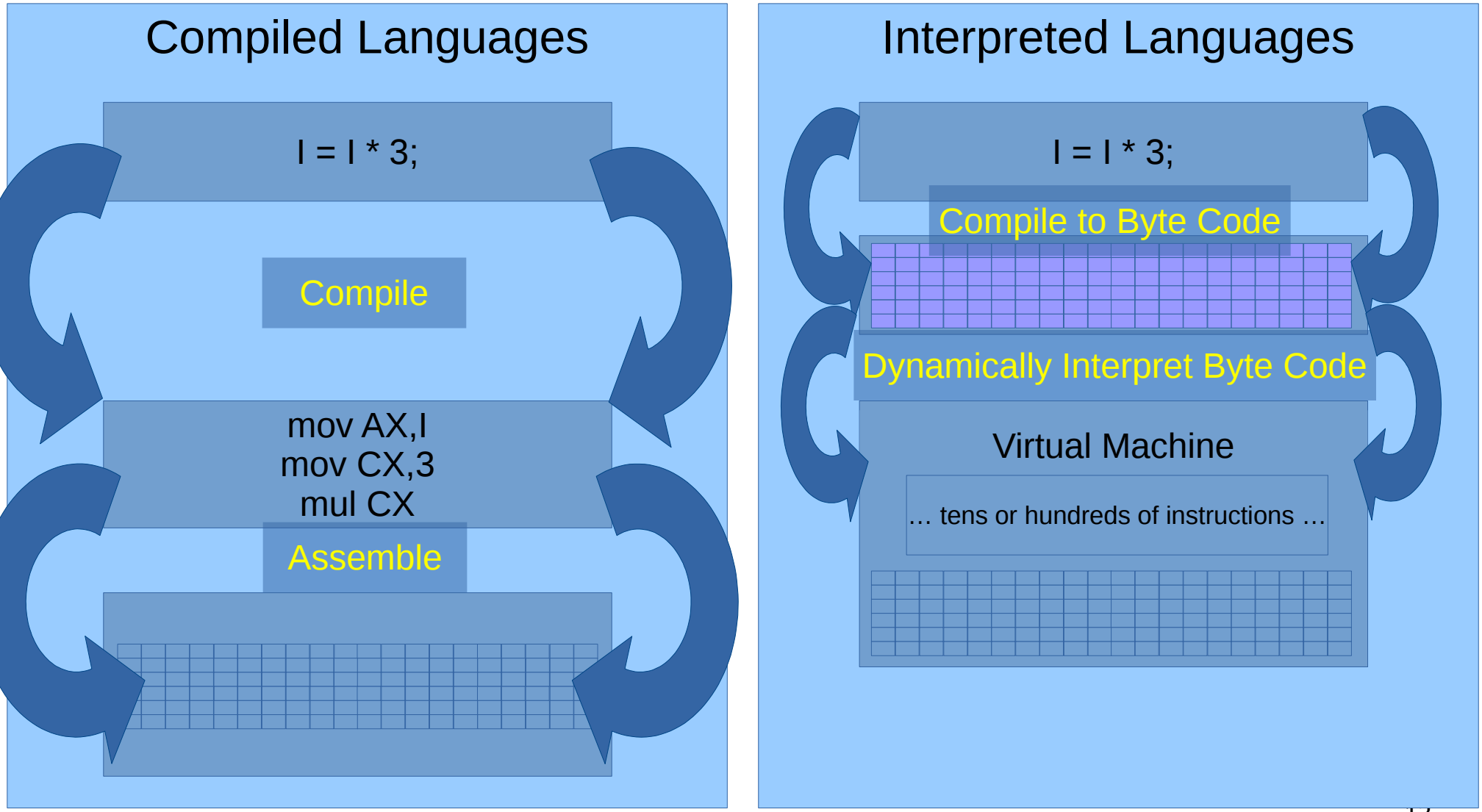
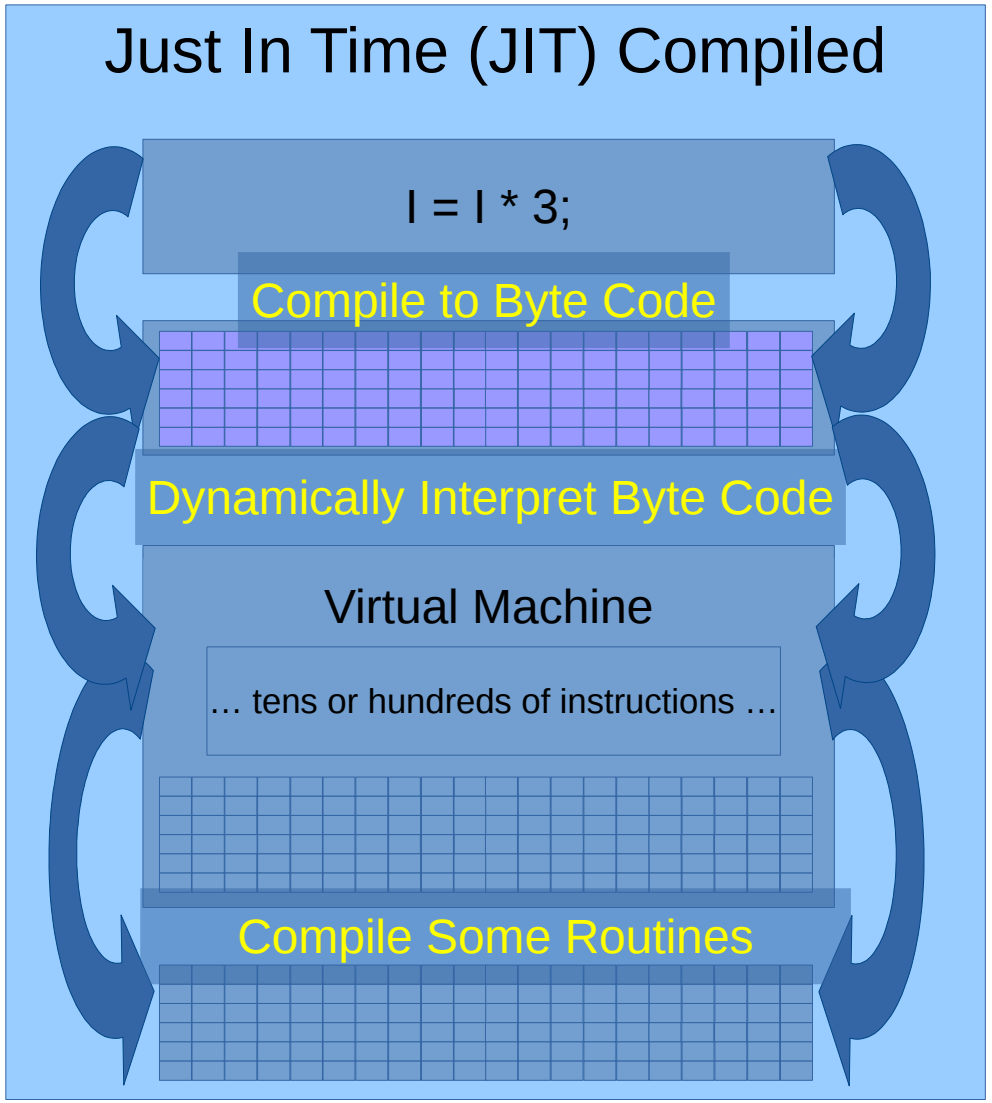
Compiled, Interpreted, and JIT
Compiled Languages

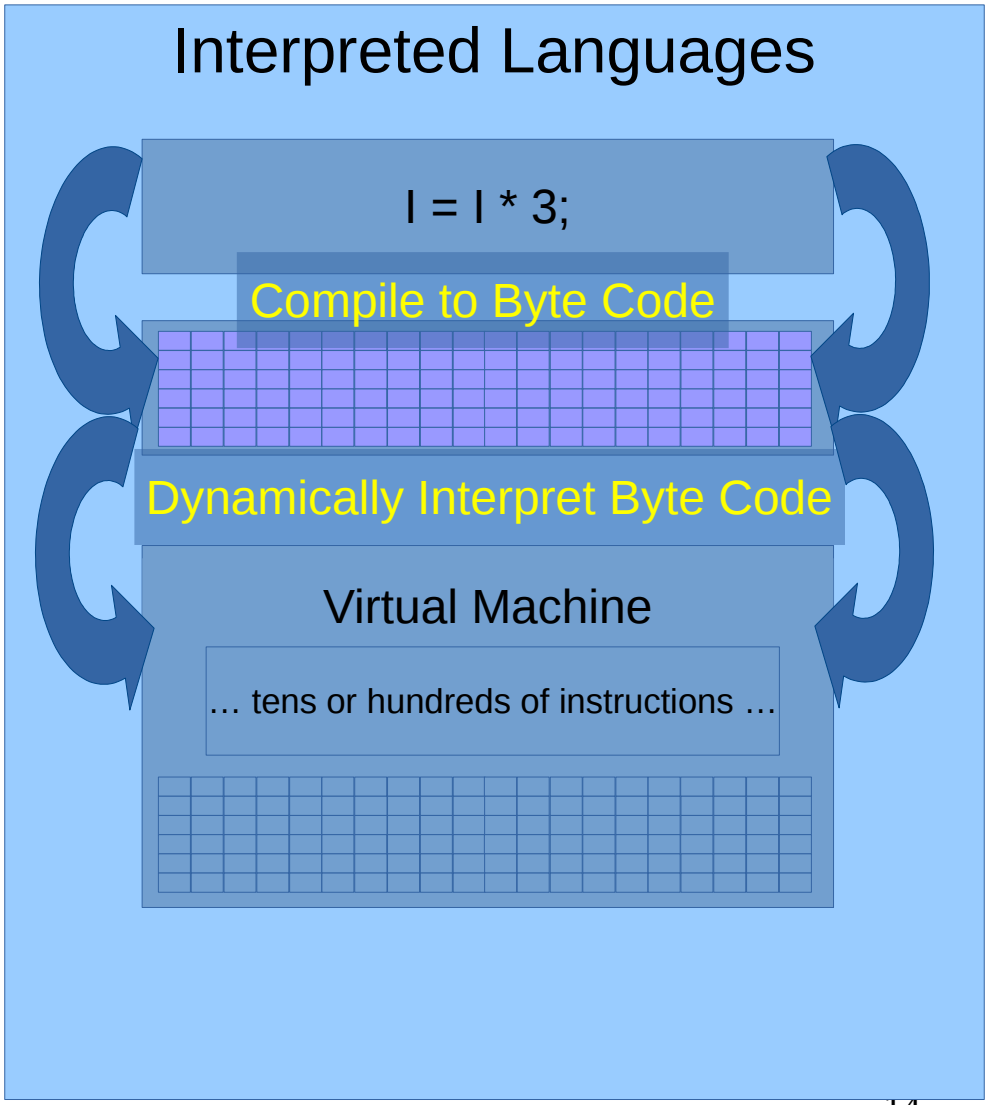


Compiled, Interpreted, and JIT
Interpreted Languages



Compiled, Interpreted, and JIT
Just In Time (JIT) Compiled



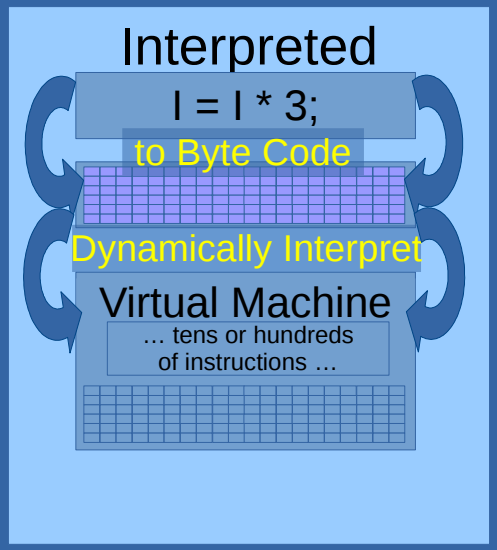


Compiled, Interpreted, and JIT

Pythons are

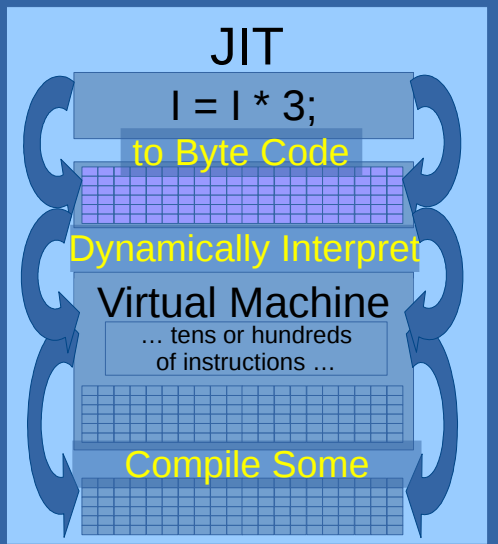
Interpreted

- CPython
  - Reference implementation



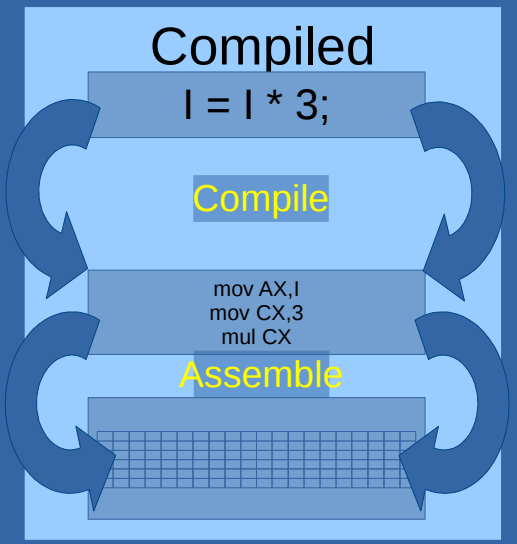
JIT+Interpreted

- Numba
- Jython
  - Uses Java Virtual Machine
- PyPy



Compiled

- Cython
  - Python to C converter



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Dynamic vs. Static
Example Python Program

```
A=1
B=1
print("I will add 1 and 1")
def print_x_plus_y(x, y):
    result = x + y
    print(f"{result}={x+y}")
print_x_plus_y(A,B)
```

- Will print:

  I will add 1 and 1

  2=2

Dynamic vs. Static
Dynamic Typing

```
A=1
B="apple"
print("I will add 1 and 1")
def print_x_plus_y(x, y):
    result = x + y
    print(f"{result}={x+y}")
print_x_plus_y(A,B)
```

- Will fail!
  - "1 + apple" is meaningless
- CPython does not know this until the program reaches:

```
result = x + y
```

Dynamic vs. Static
Static Typing

```
A=1
B="apple"
print("I will add 1 and 1")
def print_x_plus_y(
        x: int, y: int):
    result = x + y
    print(f"{result}={x+y}")
print_x_plus_y(A,B)
```

- Python will find the error as soon as it compiles the file!

Dynamic vs. Static
The Power of Dynamic Typing

```
def print_x_plus_y(x, y):
    result = x + y
```

- Same code for different types:
  - “abc” + “def” = “abcdef”
  - 1 + 1 = 2
  - [1,2,3] + [4,5,6] = [1,2,3,4,5,6]
  - … and many more …
  - All from: result = x + y

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Python is
an Ecosystem

- Python does:
  - Machine learning
  - Graphics
  - Numerics
  - etc.
- Python is an ecosystem

Python is
Glue

- ~~Python~~ does:
  - Machine learning
  - Graphics
  - Numerics
  - etc.
- Python is an ecosystem

- Many “Python” packages are wrappers around C, CUDA, Fortran, C++, etc.
  - Cython facilitates this.
- Python is glue

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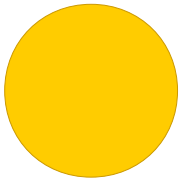
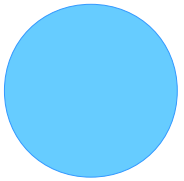
Object-Oriented Programming
Without





float x
float y
float r
float red
float green
float blue

float x
float y
float r
float red
float green
float blue

brightness_temperature(
red,green,blue)

minimum_covering_circle(
x1,y1,r1,x2,y2,r2)

saturation(
red,green,blue)

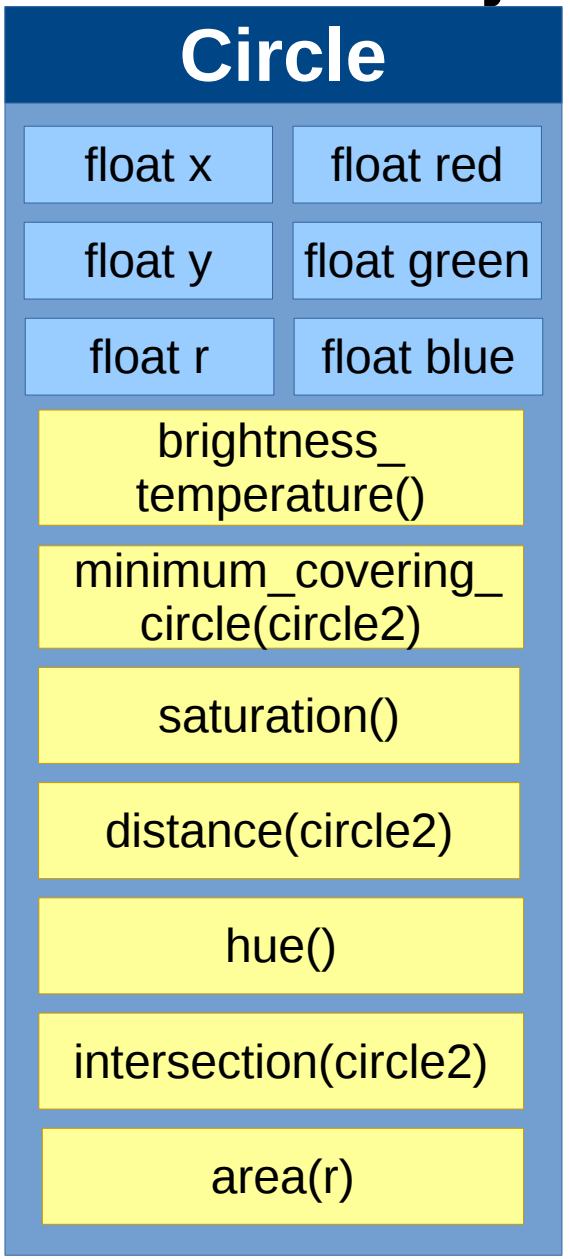
distance(
x1,y1,r1,x2,y2,r2)

hue(
red,green,blue)

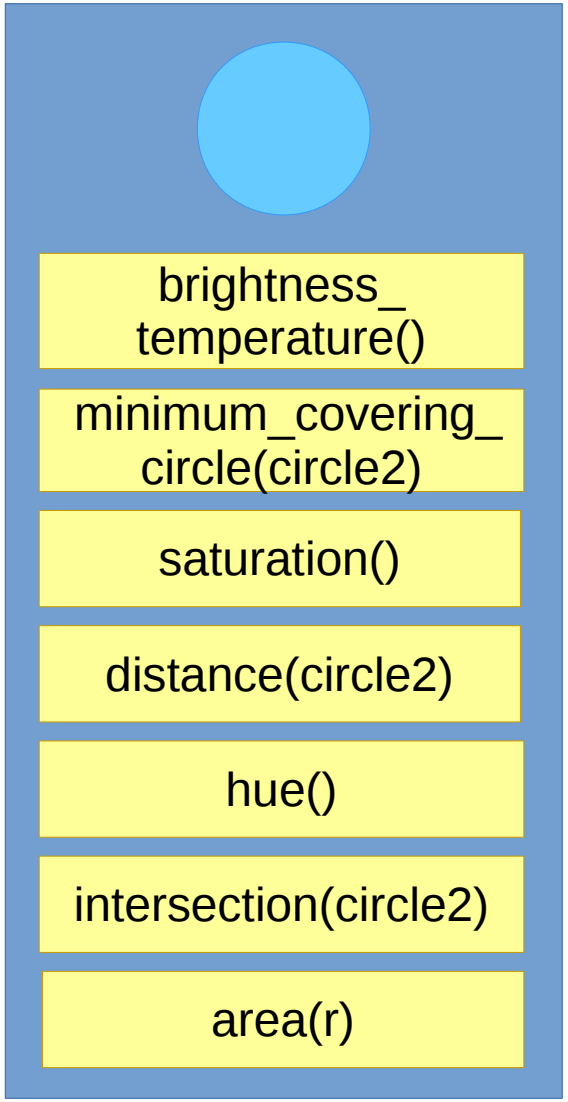
intersection(
x1,y1,r1,x2,y2,r2)

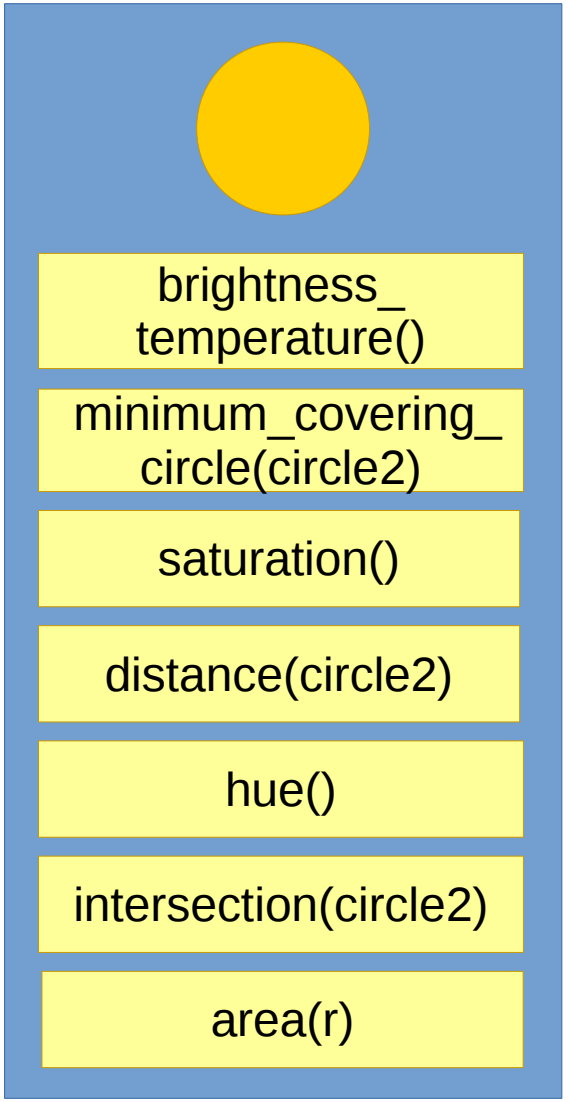
area(r)

Object-Oriented Programming
Implementation – Object's Class



Object-Oriented Programming
Interface – Object's Instance





Running Python

- Note to self:
  - ssh to jet-rsa.rdhpcs.noaa.gov
  - Use the screen session on fe4
  - See windows #3 (interactive) and #4 (script)
  - Interactive commands are in script test.py.

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Conclusion
Python is...

- An ever-changing ecosystem:
  - Multiple implementations.
  - Peer-reviewed recommendation process.
  - Numerous, redundant, actively-developed, libraries.
- Flexible:
  - Compiled, interpreted, or just-in-time.
  - A high-level language, low-level if needed.
  - Dynamically typed, scoped, etc. but can be static (to some extent).
  - Object-oriented, or not, as desired
- Glue
  - Easy to plug other languages into Python.
  - Easy to pass data between many libraries.

End.

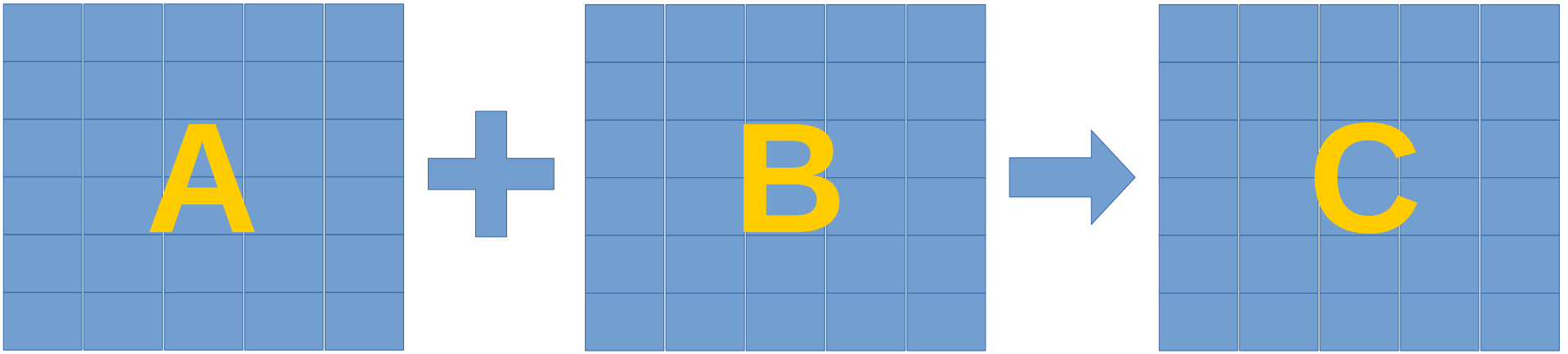
Backup Slides

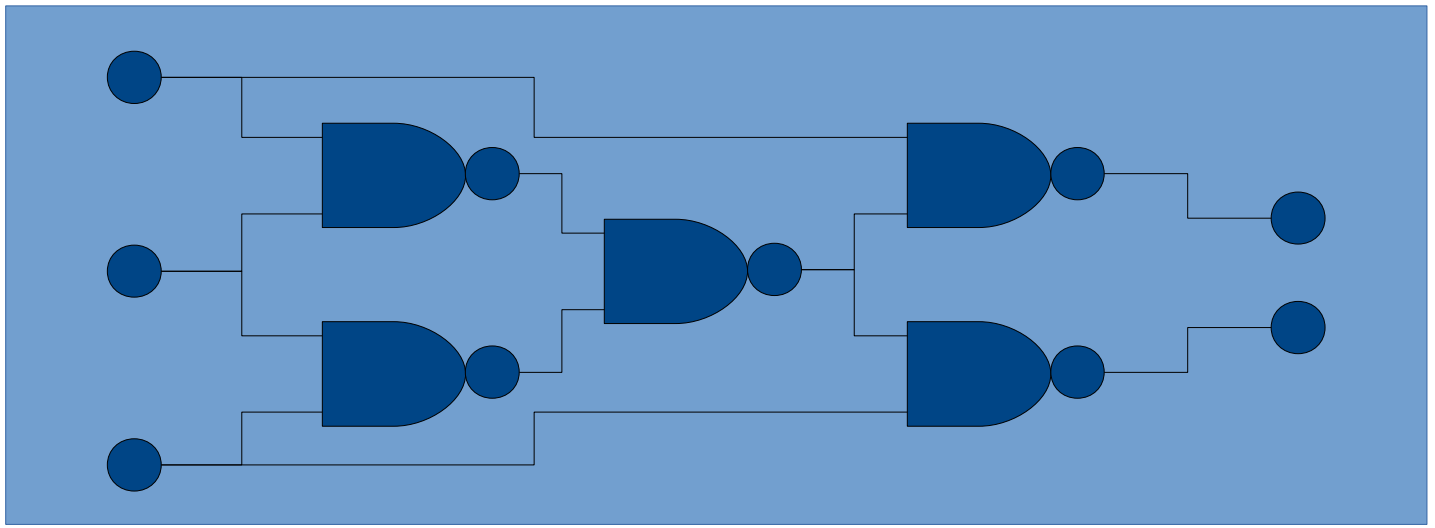
- Assembly: A Lower Level than Low-Level Languages
- NCEP Language Review, Unified Workflow Project
  - Python 2 vs. 3
  - Language Choices
  - Issues in csh
  - Other Languages

Assembly

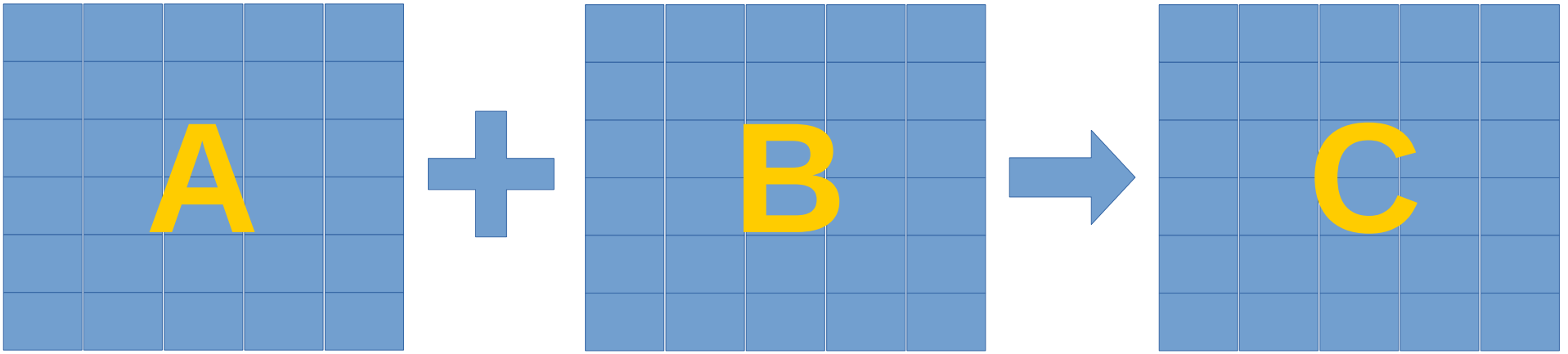
A Lower Level than Low-Level Languages

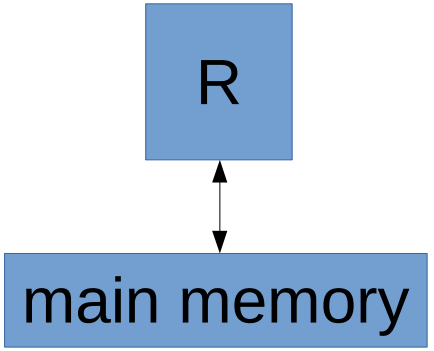
What is Python and What is it *Not*?
High-Level vs. Low-Level Languages





What is Python and What is it *Not*?
High-Level vs. Low-Level Languages





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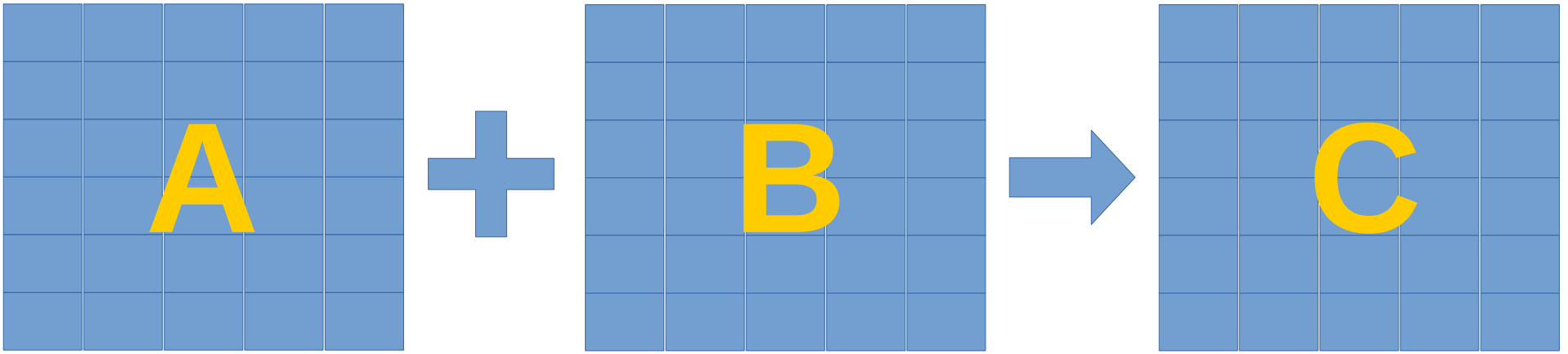

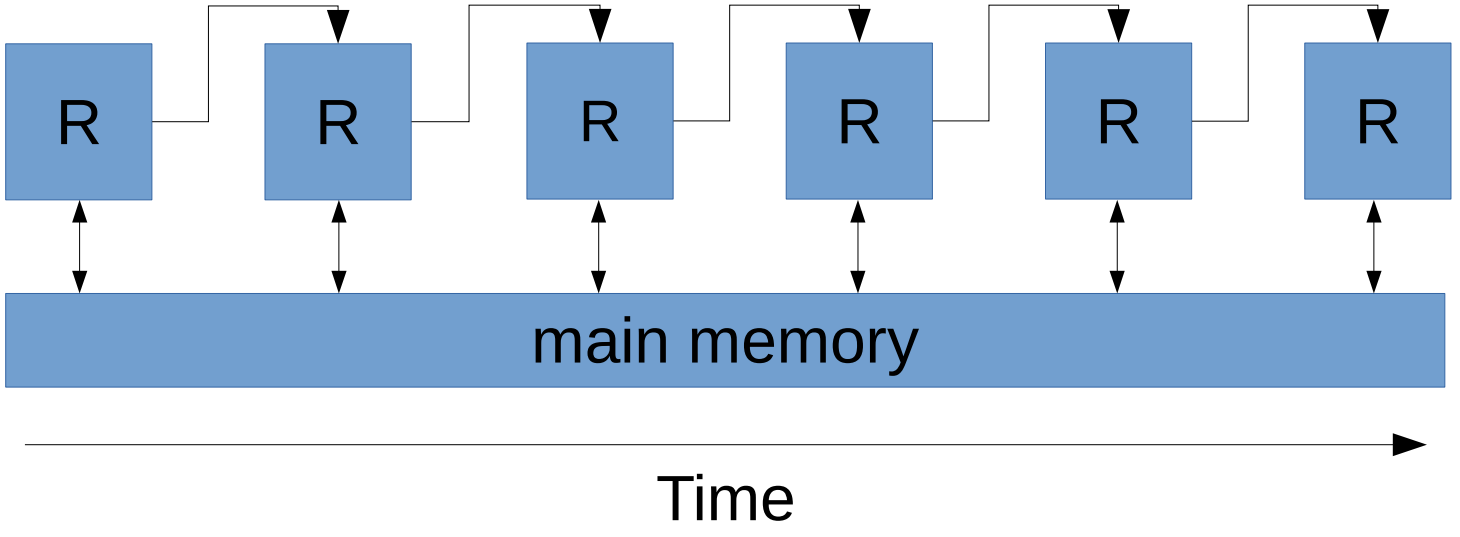

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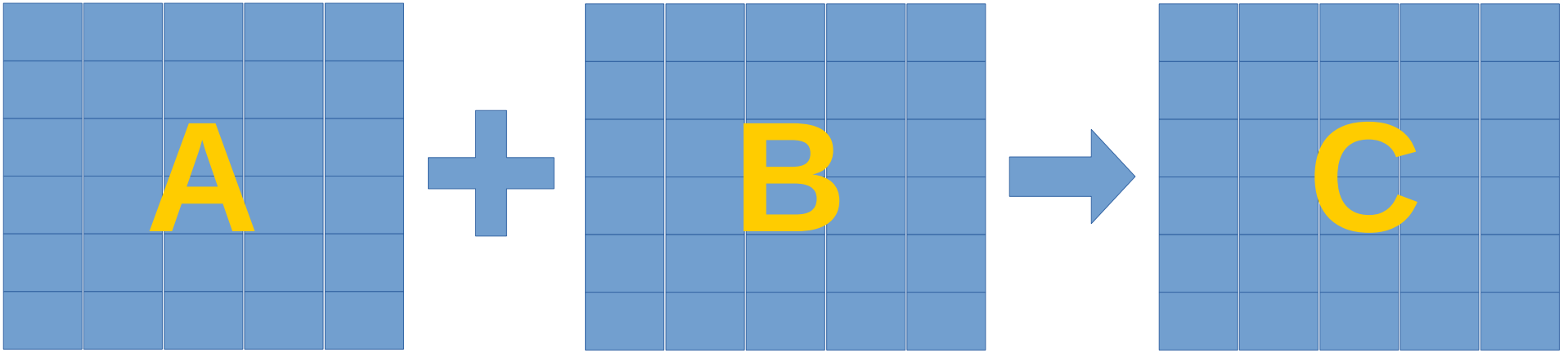
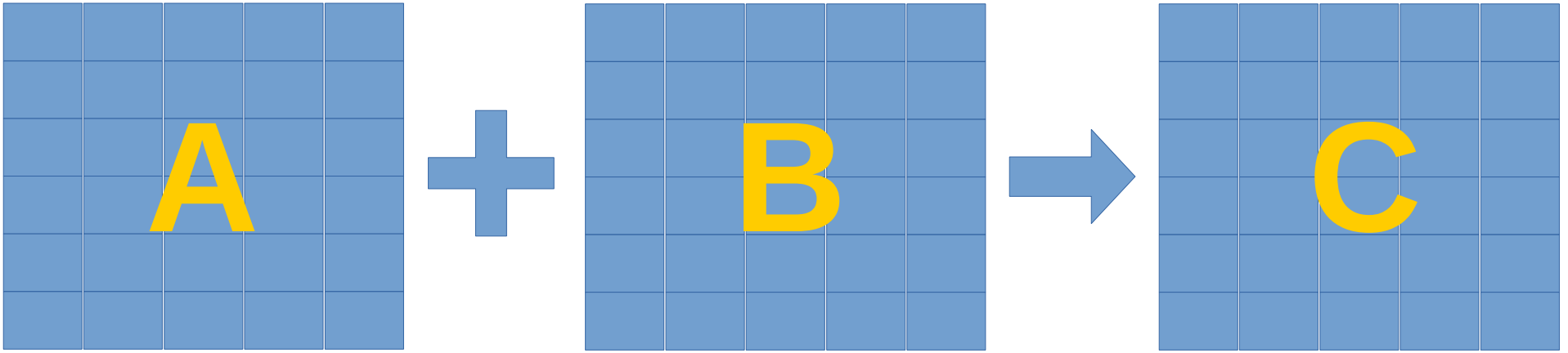


- Assembly
  - mov RAX,n
  - mov RDX,m
  - mul RDX
  - push RAX # n * m
  - mov RBX, array_a_start
  - mov RSI, array_b_start
  - mov RDI, array_c_start
  - mov RCX,0
  - loop_top:
  - mov RAX, [RBX,RCX,8]
  - mov RDX, [RSI,RCX,8]
  - add RAX,RDX
  - mov [RDI,RCX,8],RAX
  - inc RCX
  - mov RAX,[RSP]
  - cmp RAX,RCX
  - jnz loop_top

Languages: High vs Low
Low-Level Languages



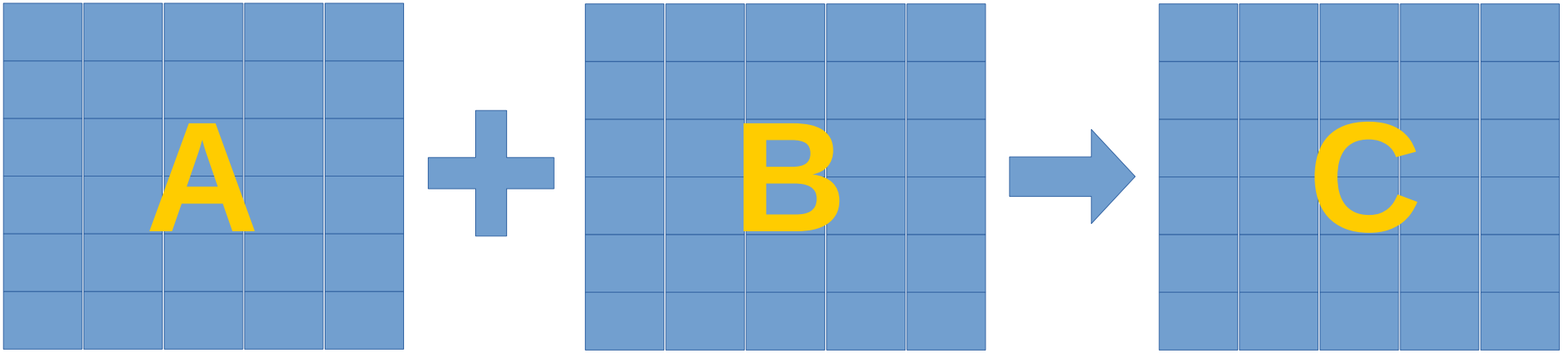
- Low-level Fortran

```
do j=1,m
  do i=1,n
    c(i,j) = a(i,j) + b(i,j)
  enddo
enddo
```

- Low-level C

```
for(j=0;j<m;j++)
  for(i=0;i<n;i++)
    c[j][i]=a[j][i]+b[j][i]
```

Languages: High vs Low
High-Level Languages



- High-level Fortran

  C = A + B

- High-level C++

  C = A + B;

- Python with numpy

  C = A + B

- High-level R

  C <- A + B

Taken, with permission, from NCEP language evaluation

Python 2 vs. 3

Python 2 vs. 3
Language Evaluation for NCEP, 2017

CPython 2.7 vs. CPython 3.6 (by NCEP priorities)

Python 2: **+0**	Python 3: **+3**	– Better exception handling → better logging
Python 2: **+0**	Python 3: **+1**	– Improved to prevent stupid mistakes
Python 2: **+2**	Python 3: **+0**	– Native ASCII becomes native Unicode
Python 2: **+0**	Python 3: **+2**	– Concise, clear, code (~1.5-5x fewer lines)
Python 2: **+0**	Python 3: **+2**	– Python 2.7 end-of-life date 2020
Python 2: **+0**	Python 3: **+0**	– Installation – trivial for either
Python 2: **+0**	Python 3: **+1**	– Training – usually python 3 these days
Python 2: **+2**	Python 3: **+9**	Totals

Python 3 Improvements
A few short examples

- Simple container classes trivial to declare:
  - Point=namedtuple(
    'Point',["x","y","z"])
- vs Python 2:

```
class Point(object):
    def __init__(self,x,y,z):
        super(Point,self).__init__(self)
        self._x,self._y,self._z = (x,y,z)
    def getx(self): return self._x
    def setx(self,x): self._x=x
    def delx(self,x): self._x=None
```

  - Python 2 example continued

```
x=property(getx,setx,delx)
def gety(self): return self._y
def sety(self,y):
    self._y=y
def dely(self,y):
    self._y=None
y=property(gety,sety,dely)
def getz(self): return self._z
def setz(self,z):
    self._z=z
def delz(self,z):
    self._z=None
z=property(getz,setz,delz)
```

Python 3 Improvements
A few short examples

- Prevent common errors:
  - Indentation tabs are parse-time syntax errors
  - super() and new/old style classes improved
    - Python 2: have to derive from “object” and pass class, self to superclass constructor

      ```
      class Point(object):
          def __init__(self,x,y,z):
              super(Point,self).__init__(self)
      ```

    - Python 3: all classes are new style, simpler super()

      ```
      class Point:
          def __init__(self,x,y,z):
              super().__init__()
      ```

Python 3 Improvements
A few short examples

- Python 3.6 added literal string interpolation
  - critical functionality present in all other scripting languages
  - Major flaw in python until 3.6
- Trivial example:
  - shells: var=(expression) ; echo “$var”
  - Ruby: var=(expression) ; puts “#{var}”
  - Perl: var=(expression) ; print “$var\n”
- And now in python 3.6:
  - Python 3.6: var=(expression) ; print(f’{var}\n’)
- Note:
  - In more complex code, this functionality dramatically reduces code complexity
  - In this trivial example, it doesn’t; this is just to demonstrate the feature.

Taken, with permission, from NCEP language evaluation

Language Choices

Capability Comparison
Categories

- Raking: DANGER - LOW – MED – HIGH

  -2 -1 +0 +1

- Portability – will my code work everywhere?
- Learning curve – for people with no knowledge
- NCEP Knowledge– what NCEP knows
- Outside Knowledge – in CS and geosciences
- Versatile – Can it simplify development and maintenance?
  - Core – standard distribution only
  - All – with common, high-reliability packages
  - (core+all) / 2
- Other – considerations specific to that language

Capability Comparison
Special Notes

- bash, ksh: *advanced language extensions* beyond sh
- sh = 100% POSIX-compliant sh
- csh lacks basic language functionality
  - Not versatile: Large parts of production suite would need to be re-implemented in executables, or call bash/ksh scripts
- python, ruby, perl – can replace many small executables with simple functions ("versatile")
- ruby "versatile" category
  - "Versatile core" is for ISO/IEC-compliant Ruby (1.8.7)
  - "Versatile all" - common extensions

Capability Comparison
Operational Languages

	Portability	Learning Curve	Existing Knowledge		Versatile (core+all)/2		Other	Total
			NCEP	Outside	core	all		
advanced ksh	Conflicting implementations	Steep	ample	minimal	med	med		**-3**
csh	Conflicting implementations	Medium	some	some	near zero	near zero		**-4**
advanced bash	Major version variance	Steep	ample	minimal	med	med		**-2**
POSIX sh	ISO Standard (POSIX)	Medium	ample	some	med	med	Always installed	**+3**
Python 2	Uniform across platforms	Teaching Language	some	ample	high	high	later	**+2**
Python 3							slide	**+4**
perl	Uniform across platforms	Steep	some	some	high	high	cryptic concise	**-1**
ruby	ISO Standard ISO/IEC 30170:2012	Teaching Language	minimal	ample	med	high		**+2.5**

Capability Comparison

What if we trained NCEP in a new language?

	Portability	Learning Curve	Existing Knowledge		Versatile (core+all)/2		Other	Total
			NCEP	Outside	core	all		
advanced ksh	Conflicting implementations	Steep	ample	minimal	med	med		**-3**
csh	Conflicting implementations	Medium	With training	some	near zero	near zero		**-3**
advanced bash	Major version variance	Steep	ample	minimal	med	med		**-2**
POSIX sh	ISO Standard (POSIX)	Medium	ample	some	med	med	Always installed	**+3**
Python 2	Uniform across platforms	Teaching Language	With training	ample	high	high	later	**+3**
Python 3							slide	**+5**
perl	Uniform across platforms	Steep	With training	some	high	high	cryptic concise	**0**
ruby	ISO Standard ISO/IEC 30170:2012	Teaching Language	With training	ample	med	high		**+4.5**

Capability Comparison
Python 2.7 vs. 3.6

Final python 2 vs. current release python 3

Python 2: **+0**	Python 3: **+3**	– Better exception handling → better logging
Python 2: **+0**	Python 3: **+1**	– Improved to prevent stupid mistakes
Python 2: **+2**	Python 3: **+0**	– Stuck with 7-bit ASCII (good for NCEP)
Python 2: **+0**	Python 3: **+2**	– Concise, clear, code (~1.5-5x fewer lines)
Python 2: **+0**	Python 3: **+2**	– Python 2.7 end-of-life date 2020
Python 2: **+0**	Python 3: **+0**	– Installation – trivial for either
Python 2: **+0**	Python 3: **+1**	– Training – usually python 3 these days
Python 2: **+2**	Python 3: **+9**	Totals

Taken, with permission, from NCEP language evaluation

Issues in csh

Issues in csh
Missing Basic Functionality

- Extremely abridged version.
  - No signal handlers
    - Cannot clean up after failed job
    - Cannot contact ecFlow server to report failed job
  - Inconsistent handling of strings with spaces
    - Special syntax needed to handle strings; syntax varies depending on context
    - Effectively, this makes it unusable for such strings
  - Cannot redirect stdout and stderr to different files

Issues in csh
Major Design Flaws

- Extremely abridged version.
  - Ad-hoc parser – must execute statements to parse them
    - More on later slides
  - Inefficient syntax for complicated expressions
    - More on later slides
  - No functions
    - Aliases are simply pasted code; they lack most capabilities of functions such as arguments, nested scopes, separate return values

Issues in csh
Ad-hoc Parser

- Inconsistent syntax – makes it error-prone
  - Excellent example from wikipedia:
    - Makes an empty file:

```
if ( ! -e myfile ) echo mytext > myfile
```

    - Puts “mytext” in a file

```
if ( ! -e myfile ) then
   echo mytext > myfile
endif
```

Issues in csh
Ad-hoc Parser

- Inconsistent syntax – makes it error-prone
  - From Berret, et.al. 2009
    - Suppose $A is undefined.
    - Statement has no effect, as it should:
      - if ($?A) echo A is defined
    - Statement fails because $A is undefined
      - if ($?A) set B = $A
    - $A is evaluated even though that statement should not be executed.

Issues in csh
Ad-hoc Parser

- From Berret, et.al. 2009
  - Error: “Variable name must contain alphanumeric characters”
    - grep "var" < file
    - grep "$var\$" <file
  - \ is not quoting the $
  - Works:
    - grep "$var"'$' < file
    - set dollar='$'
    - grep "vardollar" < file
  - Trivial in sh-like shells:
    - grep "$var\$" < file
  - Or:
    - grep "var" < file

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Other Languages

BASH

- GNU Bash project – only one implementation
- Generally backward-compatible, but:
  - Major syntactic additions make version dependence problems hard to detect
  - Built-in commands vary from version to version
  - Built-in commands added in later versions
    - Prior bash version used /bin program
    - Now it doesn’t! Functionality changed, maybe not backward-compatible

ksh

- Originated in AT&T but has multiple implementations now.
  - Significant syntactic differences
  - Differences in handling datatypes.
    - Is 013=11 or 13?
  - Built-in commands differ between versions
    - (See bash slides for details.)

Ruby

- Slower than other scripting systems, but
  - Can compile to JVM byte code for faster execution
- Fewer books and forums than Python
- More limited standard library than Python, but similar to Perl
- String processing speed comparable to Perl
- Less usage in AMS, AGU community

Perl

- Extremely concise language.
  - Great for rapid prototyping.
  - Tremendous reduction in code length for many tasks.
  - String processing speed comparable to compiled languages
- Example. Calculate pi in Perl 5:

```
$.=".$]";
$\=2/$.++-$\ for $...1e6;
print
```