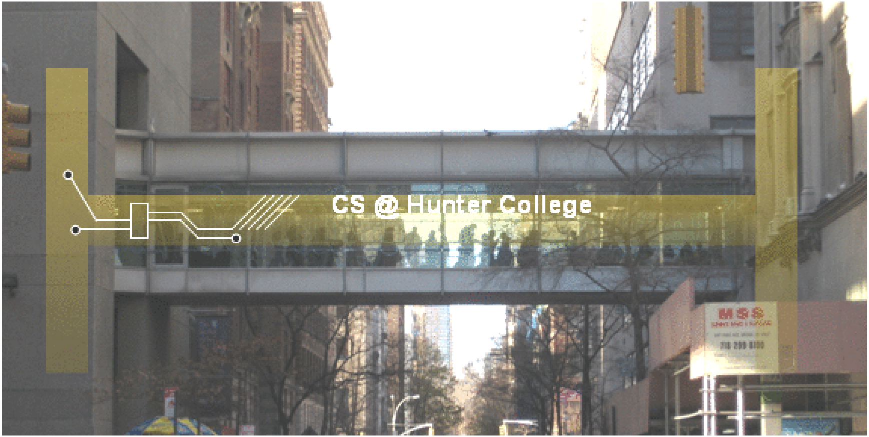
CSci 127: Introduction to Computer Science



hunter.cuny.edu/csci

Frequently Asked Questions

From email and tutoring.

- **When is the final? Is there a review sheet?**

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  Instead of a review sheet, we have:
    - *All previous final exams (and answer keys) on the website.*
    - *Our TA Lola is happy to review concepts and old exam questions.*
    - *There will be opportunity for some practice and an ungraded mock exam available on Gradescope.*

Today's Topics

- Design Patterns: Searching
- Python Recap
- Machine Language
- Machine Language: Jumps & Loops
- Binary & Hex Arithmetic
- Final Exam: Format

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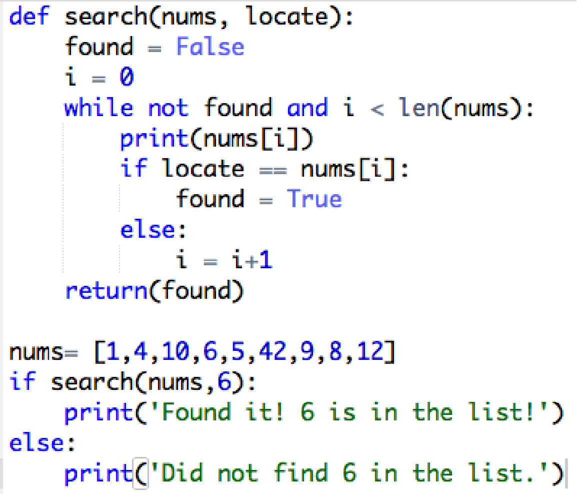
Predict what the code will do:



```python
def search(nums, locate):
    found = False
    i = 0
    while not found and i < len(nums):
        print(nums[i])
        if locate == nums[i]:
            found = True
        else:
            i = i+1
    return(found)

nums= [1,4,10,6,5,42,9,8,12]
if search(nums,6):
    print('Found it! 6 is in the list!')
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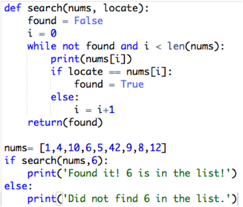
```

Python Tutor



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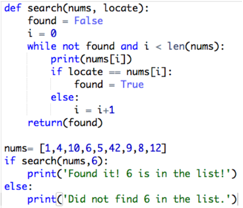
(Demo with `pythonTutor`)

Design Pattern: Linear Search



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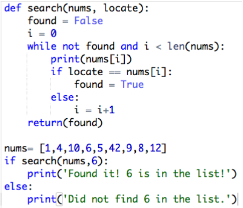

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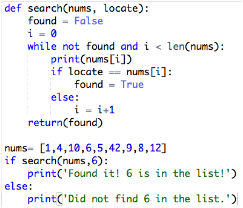

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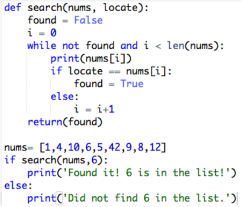

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- Example of **linear search**.
- Start at the beginning of the list.
- Look at each item, one-by-one.
- Stopping, when found, or the end of list is reached.

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- **Python Recap**
- Machine Language
- Machine Language: Jumps & Loops
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Python & Circuits Review: 9 Classes in 10 Minutes

A whirlwind tour of the semester, so far...

Class 1: print(), loops, comments, & turtles

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- Introduced comments & print():

```
#Name:  Thomas Hunter
#Date:  September 1, 2017
#This program prints:  Hello, World!

print("Hello, World!")
```

← *These lines are comments*

← *(for us, not computer to read)*

← *(this one also)*

← *Prints the string "Hello, World!" to the screen*

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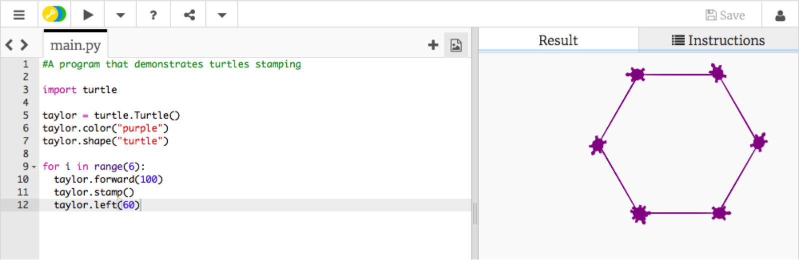
- As well as definite loops & the turtle package:



```
#A program that demonstrates turtles stamping

import turtle

taylor = turtle.Turtle()
taylor.color("purple")
taylor.shape("turtle")

for i in range(6):
  taylor.forward(100)
  taylor.stamp()
  taylor.left(60)
```

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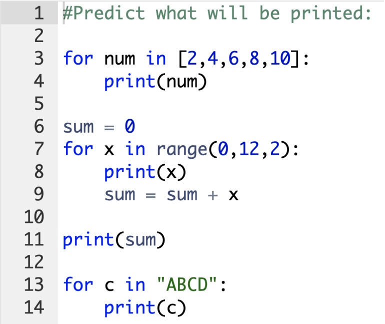
  - **class variables**: for complex objects, like turtles.
- More on loops & ranges:



```
#Predict what will be printed:

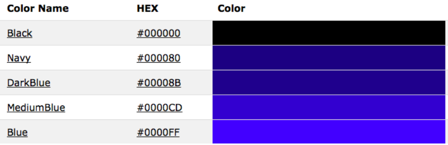
for num in [2,4,6,8,10]:
    print(num)

sum = 0
for x in range(0,12,2):
    print(x)
    sum = sum + x

print(sum)

for c in "ABCD":
    print(c)
```

Class 2: colors, hex, slices, numpy & images



Color Name	HEX	Color
Black	#000000	⬛
Navy	#000080	🟦
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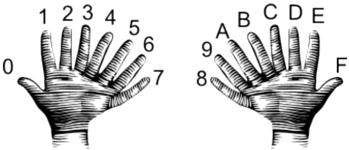

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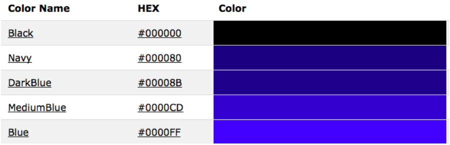

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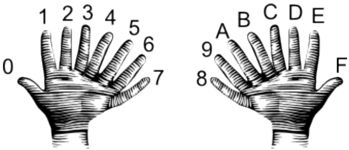

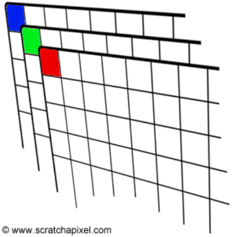

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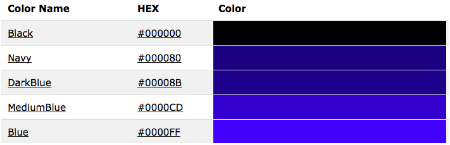

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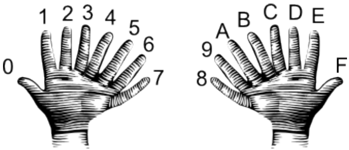

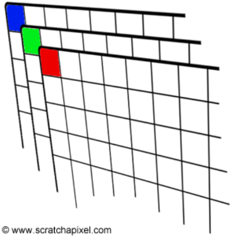

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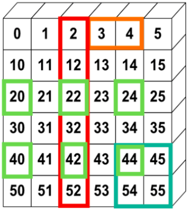
```
>>> a[0,3:5]
array([3,4])

>>> a[4:,4:]
array([[44, 45],
       [54, 55]])

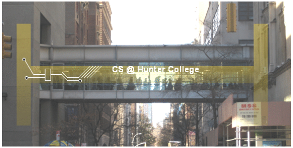
>>> a[:,2]
array([2,12,22,32,42,52])

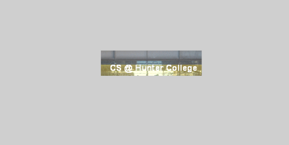
>>> a[2::2,::2]
array([[20,22,24]
       [40,42,44]])
```

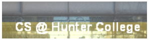


0	1	2	3	4	5
10	11	12	13	14	15
20	21	22	23	24	25
30	31	32	33	34	35
40	41	42	43	44	45
50	51	52	53	54	55

Class 3: design problem (cropping images) & decisions







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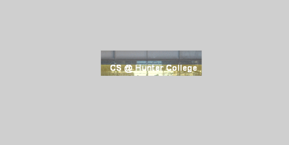

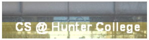

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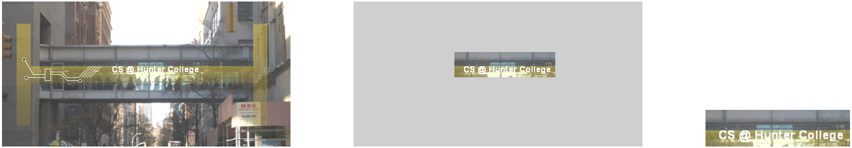

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- Next: write pseudocode.
    1. Import numpy and pyplot.
    2. Ask user for file names and dimensions for cropping.
    3. Save input file to an array.
    4. Copy the cropped portion to a new array.
    5. Save the new array to the output file.

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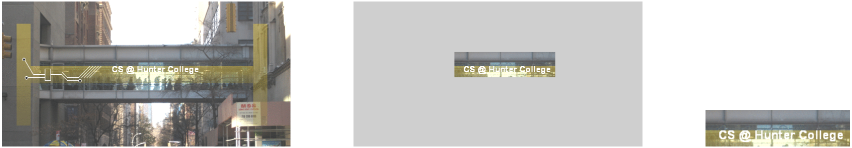

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- Next: translate to Python.

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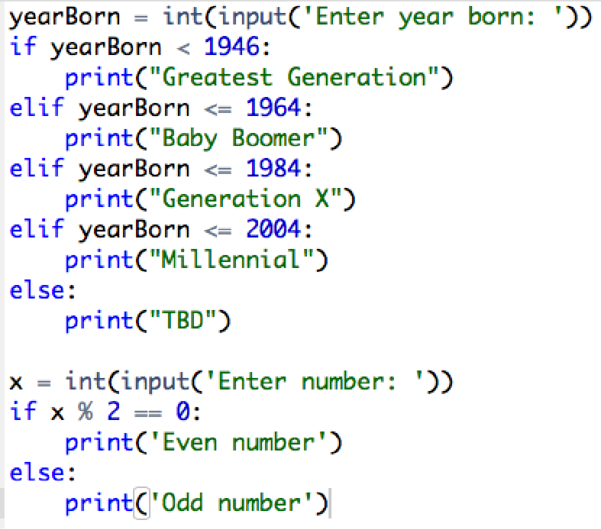
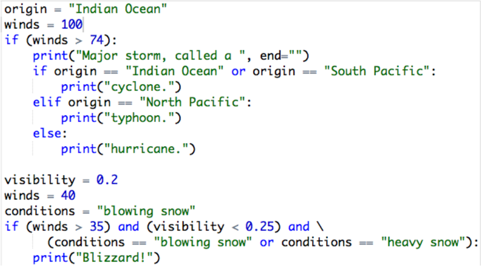


```
yearBorn = int(input('Enter year born: '))
if yearBorn < 1946:
    print("Greatest Generation")
elif yearBorn <= 1964:
    print("Baby Boomer")
elif yearBorn <= 1984:
    print("Generation X")
elif yearBorn <= 2004:
    print("Millennial")
else:
    print("TBD")

x = int(input('Enter number: '))
if x % 2 == 0:
    print('Even number')
else:
    print('Odd number')
```

Class 4: logical operators, truth tables & logical circuits

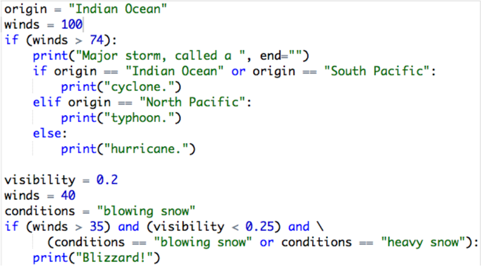


```
origin = "Indian Ocean"
winds = 100
if (winds > 74):
    print("Major storm, called a ", end="")
    if origin == "Indian Ocean" or origin == "South Pacific":
        print("cyclone.")
    elif origin == "North Pacific":
        print("typhoon.")
    else:
        print("hurricane.")

visibility = 0.2
winds = 40
conditions = "blowing snow"
if (winds > 35) and (visibility < 0.25) and \
      (conditions == "blowing snow" or conditions == "heavy snow"):
    print("Blizzard!")
```

Class 4: logical operators, truth tables & logical circuits

in1		in2	*returns:*
False	and	False	False
False	and	True	False
True	and	False	False
True	and	True	True



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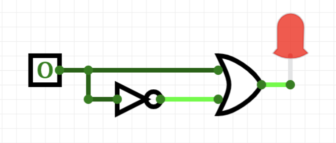
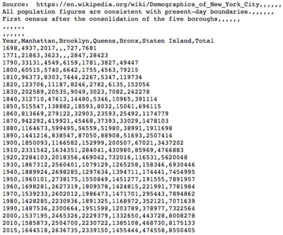


Class 5: structured data, pandas, & more design



```
Source:  https://en.wikipedia.org/wiki/Demographics_of_New_York_City,,,,,,
All population figures are consistent with present-day boundaries.,,,,,,
First census after the consolidation of the five boroughs,,,,,,
,,,,,,
,,,,,,
Year,Manhattan,Brooklyn,Queens,Bronx,Staten Island,Total
1698,4937,2017,,,727,7681
1771,21863,3623,,,2847,28423
1790,33131,4549,6159,1781,3827,49447
1800,60515,5740,6642,1755,4563,79215
1810,96373,8303,7444,2267,5347,119734
1820,123706,11187,8246,2782,6135,152056
1830,202589,20535,9049,3023,7082,242278
1840,312710,47613,14480,5346,10965,391114
1850,515547,138882,18593,8032,15061,696115
1860,813669,279122,32903,23593,25492,1174779
1870,942292,419921,45468,37393,33029,1478103
1880,1164673,599495,56559,51980,38991,1911698
1890,1441216,838547,87050,88908,51693,2507414
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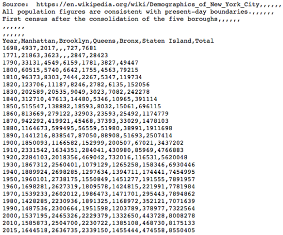
1910,2331542,1634351,284041,430980,85969,4766883
1920,2284103,2018356,469042,732016,116531,5620048
1930,1867312,2560401,1079129,1265258,158346,6930446
1940,1889924,2698285,1297634,1394711,174441,7454995
1950,1960101,2738175,1550849,1451277,191555,7891957
1960,1698281,2627319,1809578,1424815,221991,7781984
1970,1539233,2602012,1986473,1471701,295443,7894862
1980,1428285,2230936,1891325,1168972,352121,7071639
1990,1487536,2300664,1951598,1203789,378977,7322564
2000,1537195,2465326,2229379,1332650,443728,8008278
2010,1585873,2504700,2230722,1385108,468730,8175133
2015,1644518,2636735,2339150,1455444,474558,8550405
```

`nycHistPop.csv`

In Lab 6

Class 5: structured data, pandas, & more design

```
import matplotlib.pyplot as plt
import pandas as pd
```



```
Source:  https://en.wikipedia.org/wiki/Demographics_of_New_York_City,,,,,,
All population figures are consistent with present-day boundaries.,,,,,,
First census after the consolidation of the five boroughs,,,,,,
,,,,,,
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Year,Manhattan,Brooklyn,Queens,Bronx,Staten Island,Total
1698,4937,2017,,,727,7681
1771,21863,3623,,,2847,28423
1790,33131,4549,6159,1781,3827,49447
1800,60515,5740,6642,1755,4563,79215
1810,96373,8303,7444,2267,5347,119734
1820,123706,11187,8246,2782,6135,152056
1830,202589,20535,9049,3023,7082,242278
1840,312710,47613,14480,5346,10965,391114
1850,515547,138882,18593,8032,15061,696115
1860,813669,279122,32903,23593,25492,1174779
1870,942292,419921,45468,37393,33029,1478103
1880,1164673,599495,56559,51980,38991,1911698
1890,1441216,838547,87050,88908,51693,2507414
1900,1850093,1166582,152999,200507,67021,3437202
1910,2331542,1634351,284041,430980,85969,4766883
1920,2284103,2018356,469042,732016,116531,5620048
1930,1867312,2560401,1079129,1265258,158346,6930446
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1950,1960101,2738175,1550849,1451277,191555,7891957
1960,1698281,2627319,1809578,1424815,221991,7781984
1970,1539233,2602012,1986473,1471701,295443,7894862
1980,1428285,2230936,1891325,1168972,352121,7071639
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2015,1644518,2636735,2339150,1455444,474558,8550405
```

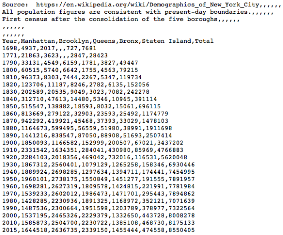
nycHistPop.csv

In Lab 6

Class 5: structured data, pandas, & more design

```
import matplotlib.pyplot as plt
import pandas as pd

pop = pd.read_csv('nycHistPop.csv',skiprows=5)
```



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```

`nycHistPop.csv`

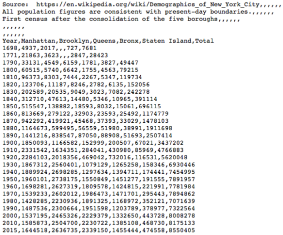
In Lab 6

Class 5: structured data, pandas, & more design

```
import matplotlib.pyplot as plt
import pandas as pd

pop = pd.read_csv('nycHistPop.csv',skiprows=5)

pop.plot(x="Year")
plt.show()
```



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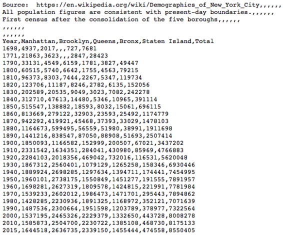
nycHistPop.csv

In Lab 6

Class 5: structured data, pandas, & more design

```
import matplotlib.pyplot as plt
import pandas as pd

pop = pd.read_csv('nycHistPop.csv',skiprows=5)
```



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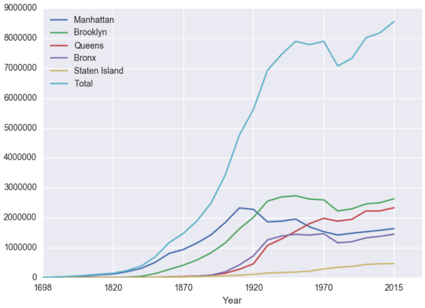
```

`nycHistPop.csv`

In Lab 6

```
pop.plot(x="Year")
plt.show()
```



Class 6: functions

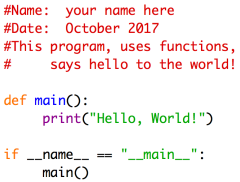
```
#Name:  your name here
#Date:  October 2017
#This program, uses functions,
#     says hello to the world!

def main():
     print("Hello, World!")

if __name__ == "__main__":
     main()
```

- Functions are a way to break code into pieces, that can be easily reused.

Class 6: functions



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- Functions are a way to break code into pieces, that can be easily reused.
- Many languages require that all code must be organized with functions.

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- The opening function is often called `main()`

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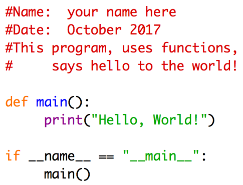
- Functions are a way to break code into pieces, that can be easily reused.
- Many languages require that all code must be organized with functions.
- The opening function is often called `main()`
- You **call** or **invoke** a function by typing its name, followed by any inputs, surrounded by parenthesis:

Class 6: functions



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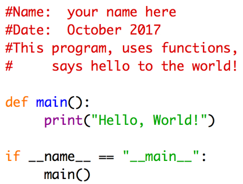
Class 6: functions



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- Functions are a way to break code into pieces, that can be easily reused.
- Many languages require that all code must be organized with functions.
- The opening function is often called `main()`
- You **call** or **invoke** a function by typing its name, followed by any inputs, surrounded by parenthesis: Example: `print("Hello", "World")`
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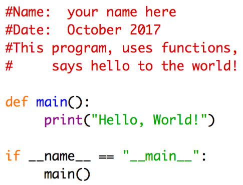
Class 6: functions



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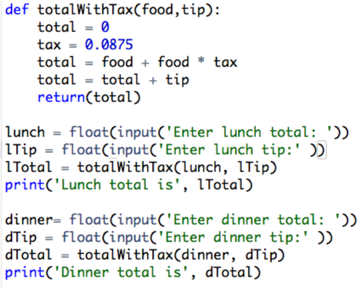
- Functions are a way to break code into pieces, that can be easily reused.
- Many languages require that all code must be organized with functions.
- The opening function is often called `main()`
- You **call** or **invoke** a function by typing its name, followed by any inputs, surrounded by parenthesis: Example: `print("Hello", "World")`
- Can write, or **define** your own functions, which are stored, until invoked or called.

Class 7: function parameters, github

- Functions can have **input parameters**.

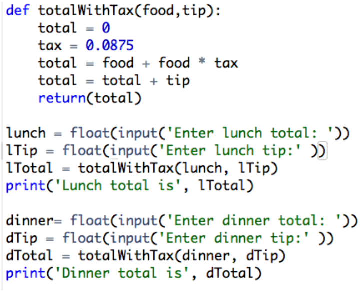


```
def totalWithTax(food,tip):
    total = 0
    tax = 0.0875
    total = food + food * tax
    total = total + tip
    return(total)

lunch = float(input('Enter lunch total: '))
lTip = float(input('Enter lunch tip:' ))
lTotal = totalWithTax(lunch, lTip)
print('Lunch total is', lTotal)

dinner= float(input('Enter dinner total: '))
dTip = float(input('Enter dinner tip:' ))
dTotal = totalWithTax(dinner, dTip)
print('Dinner total is', dTotal)
```

Class 7: function parameters, github



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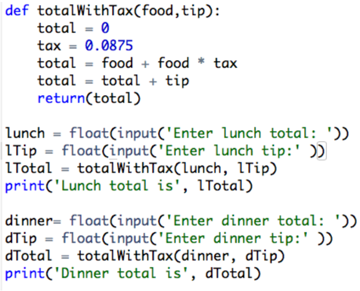
- Functions can have **input parameters**.
- Surrounded by parenthesis, both in the function definition, and in the function call (invocation).

Class 7: function parameters, github



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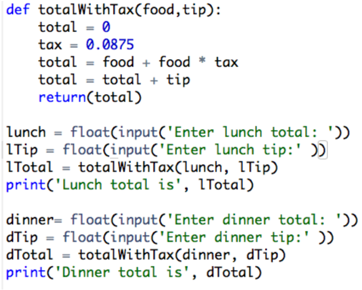
- Functions can have **input parameters**.
- Surrounded by parenthesis, both in the function definition, and in the function call (invocation).
- The “placeholders” in the function definition: **formal parameters**.

Class 7: function parameters, github



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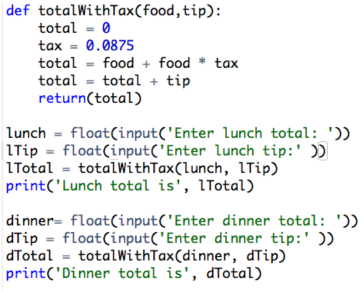
dTotal = totalWithTax(dinner, dTip)
print('Dinner total is', dTotal)
```

- Functions can have **input parameters**.
- Surrounded by parenthesis, both in the function definition, and in the function call (invocation).
- The “placeholders” in the function definition: **formal parameters**.
- The ones in the function call: **actual parameters**

Class 7: function parameters, github



```
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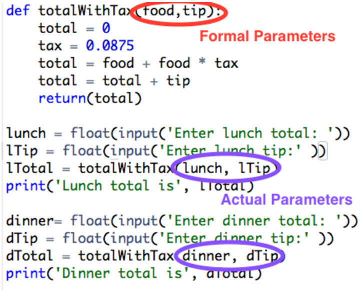
```

- Functions can have **input parameters**.
- Surrounded by parenthesis, both in the function definition, and in the function call (invocation).
- The "placeholders" in the function definition: **formal parameters**.
- The ones in the function call: **actual parameters**
- Functions can also **return values** to where it was called.

Class 7: function parameters, github



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print('Dinner total is', dTotal)
```

- Functions can have **input parameters**.
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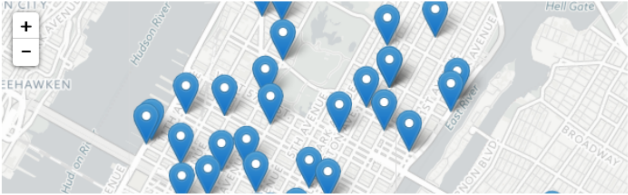
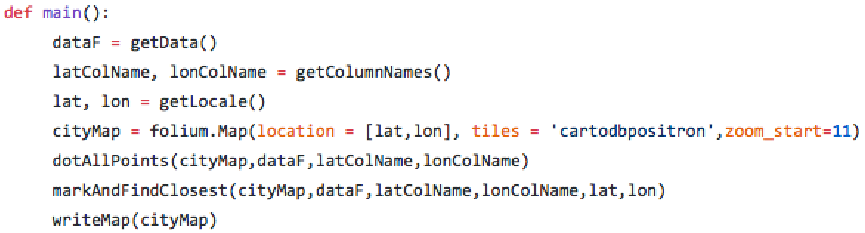
- The "placeholders" in the function definition: **formal parameters**.
- The ones in the function call: **actual parameters**.
- Functions can also **return values** to where it was called.

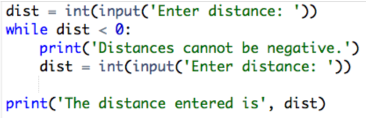
Class 8: top-down design, folium, loops, and random()





```
def main():
     dataF = getData()
     latColName, lonColName = getColumnNames()
     lat, lon = getLocale()
     cityMap = folium.Map(location = [lat,lon], tiles = 'cartodbpositron',zoom_start=11)
     dotAllPoints(cityMap,dataF,latColName,lonColName)
     markAndFindClosest(cityMap,dataF,latColName,lonColName,lat,lon)
     writeMap(cityMap)
```

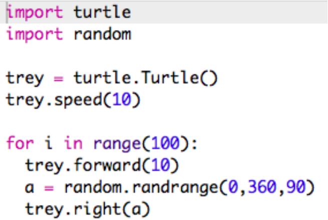
Class 9: more on loops, max design pattern, random()



```
dist = int(input('Enter distance: '))
while dist < 0:
    print('Distances cannot be negative.')
    dist = int(input('Enter distance: '))

print('The distance entered is', dist)
```

- Indefinite (while) loops allow you to repeat a block of code as long as a condition holds.

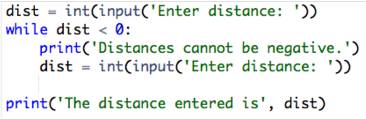


```
import turtle
import random

trey = turtle.Turtle()
trey.speed(10)

for i in range(100):
  trey.forward(10)
  a = random.randrange(0,360,90)
  trey.right(a)
```

Class 9: more on loops, max design pattern, random()



```
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while dist < 0:
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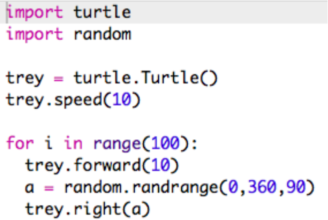
print('The distance entered is', dist)
```

- Indefinite (while) loops allow you to repeat a block of code as long as a condition holds.
- Very useful for checking user input for correctness.

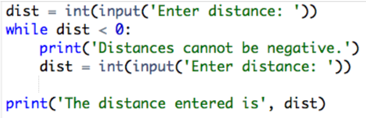


```
import turtle
import random

trey = turtle.Turtle()
trey.speed(10)

for i in range(100):
  trey.forward(10)
  a = random.randrange(0,360,90)
  trey.right(a)
```

Class 9: more on loops, max design pattern, random()



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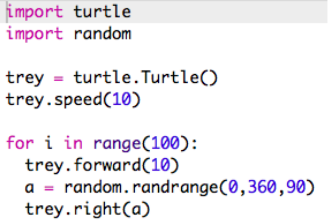

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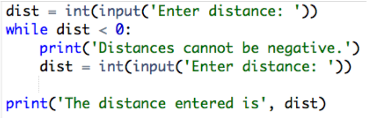
Class 9: more on loops, max design pattern, random()



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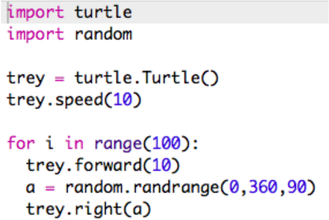
```



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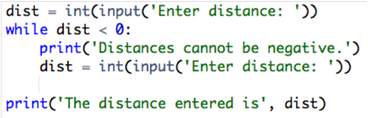

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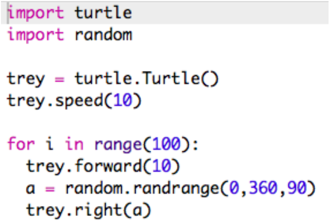

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- Indefinite (while) loops allow you to repeat a block of code as long as a condition holds.
- Very useful for checking user input for correctness.
- Python's built-in random package has useful methods for generating random whole numbers and real numbers.
- To use, must include: `import random`.
- The max design pattern provides a template for finding maximum value from a list.

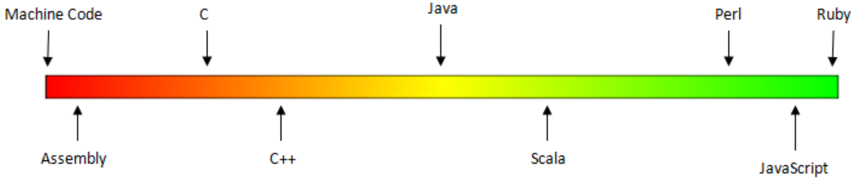
Python & Circuits Review: 9 Classes in 10 Minutes

- Input/Output (I/O): `input()` and `print()`; pandas for CSV files
- Types:
  - Primitive: int, float, bool, string;
  - Container: lists (but not dictionaries/hashes or tuples)
- Objects: turtles (used but did not design our own)
- Loops: definite & indefinite
- Conditionals: if-elif-else
- Logical Expressions & Circuits
- Functions: parameters & returns
- Packages:
  - Built-in: turtle, math, random
  - Popular: numpy, matplotlib, pandas, folium

Today's Topics

- Design Patterns: Searching
- Python Recap
- **Machine Language**
- Machine Language: Jumps & Loops
- Binary & Hex Arithmetic
- Final Exam: Format

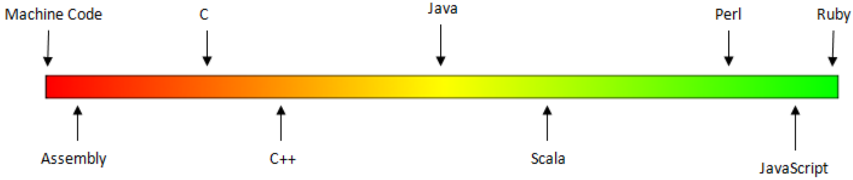
Low-Level vs. High-Level Languages



(codeCommit)

- Can view programming languages on a continuum.

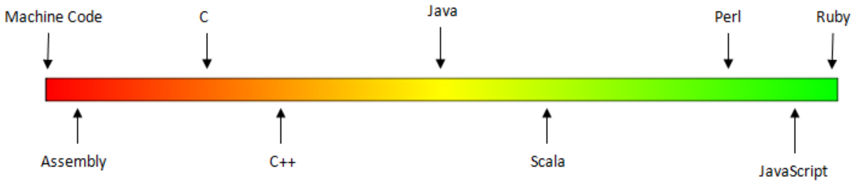
Low-Level vs. High-Level Languages



(codeCommit)

- Can view programming languages on a continuum.
- Those that directly access machine instructions & memory and have little abstraction are **low-level languages**

Low-Level vs. High-Level Languages



(codeCommit)

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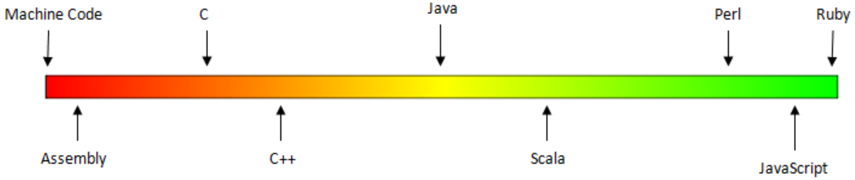
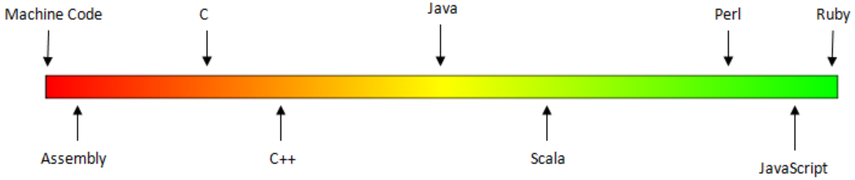
Low-Level vs. High-Level Languages



(codeCommit)

- Can view programming languages on a continuum.
- Those that directly access machine instructions & memory and have little abstraction are **low-level languages** (e.g. machine language, assembly language).
- Those that have strong abstraction (allow programming paradigms independent of the machine details, such as complex variables, functions and looping that do not translate directly into machine code) are called **high-level languages**.

Low-Level vs. High-Level Languages



(codeCommit)

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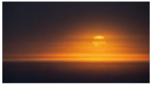
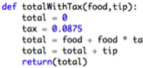
- Those that have strong abstraction (allow programming paradigms independent of the machine details, such as complex variables, functions and looping that do not translate directly into machine code) are called **high-level languages**.
- Some languages, like C, are in between– allowing both low level access and high level data structures.

Processing

Dies ist ein Blindtext. An ihm lässt sich vieles über die Schrift ablesen, in der er gesetzt ist. Auf den ersten Blick wird der Grauwert der Schriftfläche sichtbar. Dann kann man prüfen, wie gut die Schrift zu lesen ist und wie sie auf den Leser wirkt. Dies ist ein Blindtext. An ihm lässt sich

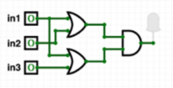




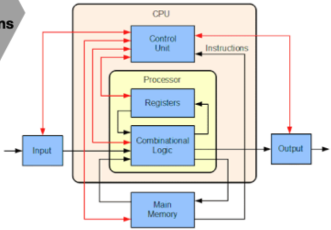
```
def totalWithTax(food,tip):
    total = 0
    tax = 0.0875
    total = food + food * tax
    total = total + tip
    return(total)
```

Data
&
Instructions

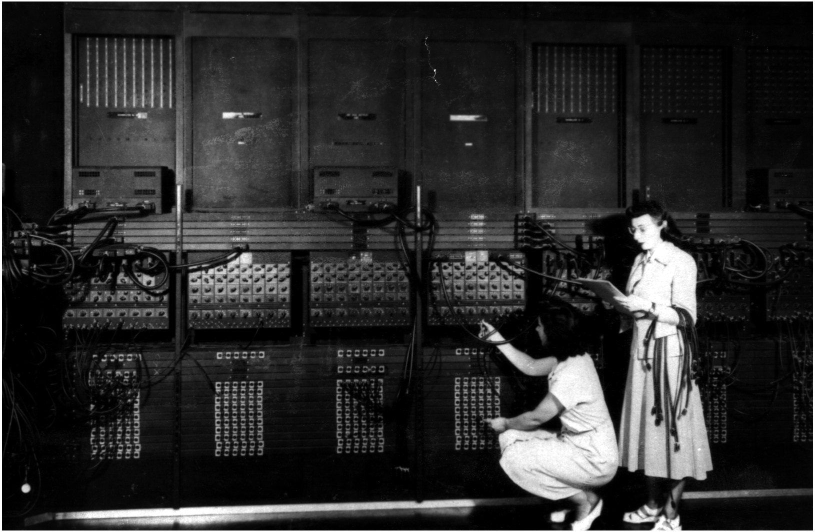
Data
&
Instructions



Circuits (switches)
On/Off 1/0 Logic
Billions of switches/bits

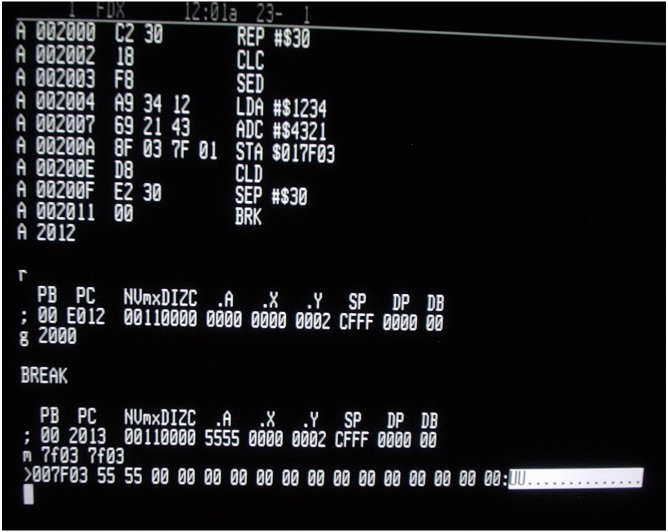


Machine Language



(Ruth Gordon & Ester Gerston programming the ENIAC, UPenn)

Machine Language



```
        1  FDX        12:01a  23-   1
A 002000  C2 30          REP #$30
A 002002  18             CLC
A 002003  F8             SED
A 002004  A9 34 12       LDA #$1234
A 002007  69 21 43       ADC #$4321
A 00200A  8F 03 7F 01    STA $017F03
A 00200E  D8             CLD
A 00200F  E2 30          SEP #$30
A 002011  00             BRK
A 2012

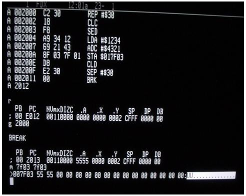
r
  PB  PC   NVmxDIZC  .A   .X   .Y   SP   DP  DB
; 00 E012  00110000 0000 0000 0002 CFFF 0000 00
g 2000

BREAK

  PB  PC   NVmxDIZC  .A   .X   .Y   SP   DP  DB
; 00 2013  00110000 5555 0000 0002 CFFF 0000 00
m 7f03 7f03
>007F03 55 55 00 00 00 00 00 00 00 00 00 00 00 00 00 00:UU..............
```

(wiki)

Machine Language



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    1  FDX       12:01a  23-  1
A 002000  C2 30        REP #$30
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(wiki)

- We will be writing programs in a simplified machine language, WeMIPS.

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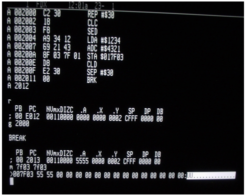

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(wiki)

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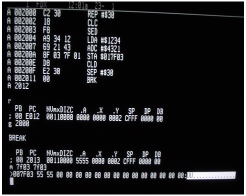
Machine Language



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(wiki)

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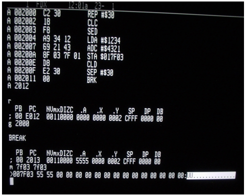
- Due to its small set of commands, processors can be designed to run those commands very efficiently.

Machine Language



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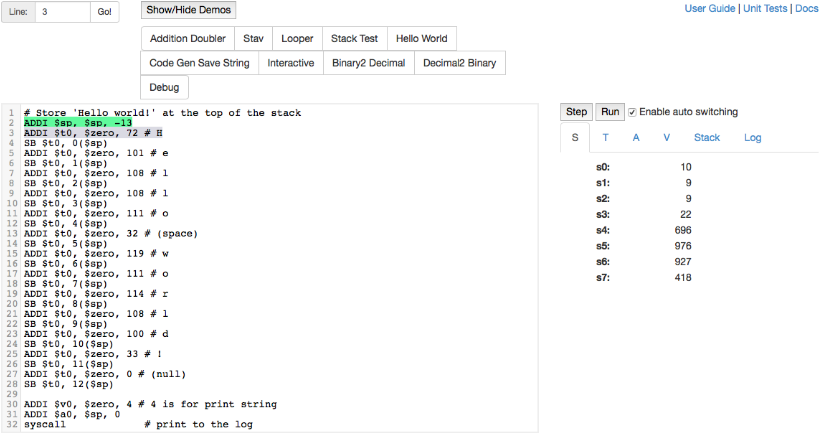
- More in future architecture classes....

"Hello World!" in Simplified Machine Language



Line: 3

☑ Enable auto switching

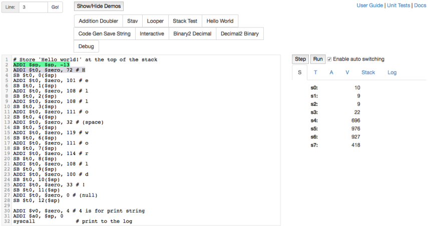
```
# Store 'Hello world!' at the top of the stack
ADDI $sp, $sp, -13
ADDI $t0, $zero, 72 # H
SB $t0, 0($sp)
ADDI $t0, $zero, 101 # e
SB $t0, 1($sp)
ADDI $t0, $zero, 108 # l
SB $t0, 2($sp)
ADDI $t0, $zero, 108 # l
SB $t0, 3($sp)
ADDI $t0, $zero, 111 # o
SB $t0, 4($sp)
ADDI $t0, $zero, 32 # (space)
SB $t0, 5($sp)
ADDI $t0, $zero, 119 # w
SB $t0, 6($sp)
ADDI $t0, $zero, 111 # o
SB $t0, 7($sp)
ADDI $t0, $zero, 114 # r
SB $t0, 8($sp)
ADDI $t0, $zero, 108 # l
SB $t0, 9($sp)
ADDI $t0, $zero, 100 # d
SB $t0, 10($sp)
ADDI $t0, $zero, 33 # !
SB $t0, 11($sp)
ADDI $t0, $zero, 0 # (null)
SB $t0, 12($sp)

ADDI $v0, $zero, 4 # 4 is for print string
ADDI $a0, $sp, 0
syscall             # print to the log
```

s0:	10
s1:	9
s2:	9
s3:	22
s4:	696
s5:	976
s6:	927
s7:	418

(WeMIPS)

WeMIPS



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SB $t0, 8($sp)
ADDI $t0, $zero, 108 # l
SB $t0, 9($sp)
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ADDI $t0, $zero, 33 # !
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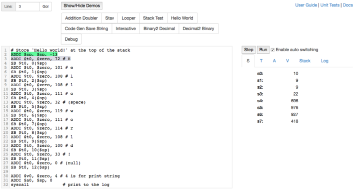
s5:    976
s6:    927
s7:    418
```

(Demo with WeMIPS)

MIPS Commands



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SB $t0, 10($sp)
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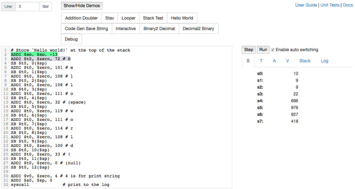
```
s0:    10
s1:     9
s2:     9
s3:    22
s4:   696
s5:   976
s6:   927
s7:   418
```

- **Registers:** locations for storing information that can be quickly accessed.

MIPS Commands



Line: 3 Go!

☑ Enable auto switching

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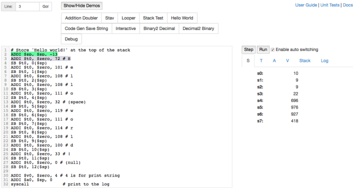
s1:	9
s2:	9
s3:	22
s4:	696
s5:	976
s6:	927
s7:	418

- **Registers:** locations for storing information that can be quickly accessed. Names start with '$': `$s0`, `$s1`, `$t0`, `$t1`,...

MIPS Commands



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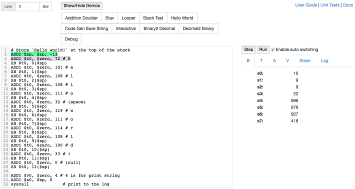
ADDI $sp, $sp, -13
ADDI $t0, $zero, 72 # H
SB $t0, 0($sp)
ADDI $t0, $zero, 101 # e
SB $t0, 1($sp)
ADDI $t0, $zero, 108 # l
SB $t0, 2($sp)
ADDI $t0, $zero, 108 # l
SB $t0, 3($sp)
ADDI $t0, $zero, 111 # o
SB $t0, 4($sp)
ADDI $t0, $zero, 32 # (space)
SB $t0, 5($sp)
ADDI $t0, $zero, 119 # w
SB $t0, 6($sp)
ADDI $t0, $zero, 111 # o
SB $t0, 7($sp)
ADDI $t0, $zero, 114 # r
SB $t0, 8($sp)
ADDI $t0, $zero, 108 # l
SB $t0, 9($sp)
ADDI $t0, $zero, 100 # d
SB $t0, 10($sp)
ADDI $t0, $zero, 33 # !
SB $t0, 11($sp)
ADDI $t0, $zero, 0 # (null)
SB $t0, 12($sp)

ADDI $v0, $zero, 4 # 4 is for print string
ADDI $a0, $sp, 0
syscall            # print to the log
```

```
s0:   10
s1:    9
s2:    9
s3:   22
s4:  696
s5:  976
s6:  927
s7:  418
```

- **Registers:** locations for storing information that can be quickly accessed. Names start with '$': `$s0`, `$s1`, `$t0`, `$t1`,...
- **R Instructions:** Commands that use data in the registers:

MIPS Commands



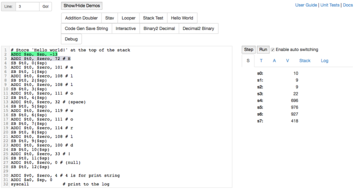
```
# Store 'Hello world!' at the top of the stack
ADDI $sp, $sp, -13
ADDI $t0, $zero, 72 # H
SB $t0, 0($sp)
ADDI $t0, $zero, 101 # e
SB $t0, 1($sp)
ADDI $t0, $zero, 108 # l
SB $t0, 2($sp)
ADDI $t0, $zero, 108 # l
SB $t0, 3($sp)
ADDI $t0, $zero, 111 # o
SB $t0, 4($sp)
ADDI $t0, $zero, 32 # (space)
SB $t0, 5($sp)
ADDI $t0, $zero, 119 # w
SB $t0, 6($sp)
ADDI $t0, $zero, 111 # o
SB $t0, 7($sp)
ADDI $t0, $zero, 114 # r
SB $t0, 8($sp)
ADDI $t0, $zero, 108 # l
SB $t0, 9($sp)
ADDI $t0, $zero, 100 # d
SB $t0, 10($sp)
ADDI $t0, $zero, 33 # !
SB $t0, 11($sp)
ADDI $t0, $zero, 0 # (null)
SB $t0, 12($sp)

ADDI $v0, $zero, 4 # 4 is for print string
ADDI $a0, $sp, 0
syscall             # print to the log
```

s0:	10
s1:	9
s2:	9
s3:	22
s4:	696
s5:	976
s6:	927
s7:	418

- **Registers:** locations for storing information that can be quickly accessed. Names start with '$': `$s0`, `$s1`, `$t0`, `$t1`,...
- **R Instructions:** Commands that use data in the registers: `add $s1, $s2, $s3`

MIPS Commands



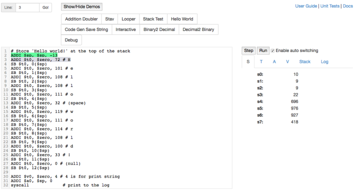
```
# Store 'Hello world!' at the top of the stack
ADDI $sp, $sp, -13
ADDI $t0, $zero, 72 # H
SB $t0, 0($sp)
ADDI $t0, $zero, 101 # e
SB $t0, 1($sp)
ADDI $t0, $zero, 108 # l
SB $t0, 2($sp)
ADDI $t0, $zero, 108 # l
SB $t0, 3($sp)
ADDI $t0, $zero, 111 # o
SB $t0, 4($sp)
ADDI $t0, $zero, 32 # (space)
SB $t0, 5($sp)
ADDI $t0, $zero, 119 # w
SB $t0, 6($sp)
ADDI $t0, $zero, 111 # o
SB $t0, 7($sp)
ADDI $t0, $zero, 114 # r
SB $t0, 8($sp)
ADDI $t0, $zero, 108 # l
SB $t0, 9($sp)
ADDI $t0, $zero, 100 # d
SB $t0, 10($sp)
ADDI $t0, $zero, 33 # !
SB $t0, 11($sp)
ADDI $t0, $zero, 0 # (null)
SB $t0, 12($sp)

ADDI $v0, $zero, 4 # 4 is for print string
ADDI $a0, $sp, 0
syscall            # print to the log
```

s0:	10
s1:	9
s2:	9
s3:	22
s4:	696
s5:	976
s6:	927
s7:	418

- **Registers:** locations for storing information that can be quickly accessed. Names start with '$': `$s0`, `$s1`, `$t0`, `$t1`,...
- **R Instructions:** Commands that use data in the registers:
  `add $s1, $s2, $s3` (Basic form: `OP rd, rs, rt`)
- **I Instructions:** instructions that also use intermediate values.

MIPS Commands



Line: 3

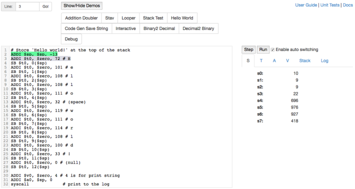
```
# Store 'Hello world!' at the top of the stack
ADDI $sp, $sp, -13
ADDI $t0, $zero, 72 # H
SB $t0, 0($sp)
ADDI $t0, $zero, 101 # e
SB $t0, 1($sp)
ADDI $t0, $zero, 108 # l
SB $t0, 2($sp)
ADDI $t0, $zero, 108 # l
SB $t0, 3($sp)
ADDI $t0, $zero, 111 # o
SB $t0, 4($sp)
ADDI $t0, $zero, 32 # (space)
SB $t0, 5($sp)
ADDI $t0, $zero, 119 # w
SB $t0, 6($sp)
ADDI $t0, $zero, 111 # o
SB $t0, 7($sp)
ADDI $t0, $zero, 114 # r
SB $t0, 8($sp)
ADDI $t0, $zero, 108 # l
SB $t0, 9($sp)
ADDI $t0, $zero, 100 # d
SB $t0, 10($sp)
ADDI $t0, $zero, 33 # !
SB $t0, 11($sp)
ADDI $t0, $zero, 0 # (null)
SB $t0, 12($sp)

ADDI $v0, $zero, 4 # 4 is for print string
ADDI $a0, $sp, 0
syscall             # print to the log
```

```
s0:    10
s1:     9
s2:     9
s3:    22
s4:   696
s5:   976
s6:   927
s7:   418
```

- **Registers:** locations for storing information that can be quickly accessed. Names start with '\$': `$s0`, `$s1`, `$t0`, `$t1`,...
- **R Instructions:** Commands that use data in the registers:
  `add $s1, $s2, $s3` (Basic form: `OP rd, rs, rt`)
- **I Instructions:** instructions that also use intermediate values.
  `addi $s1, $s2, 100`

MIPS Commands



Line: 3

☑ Enable auto switching

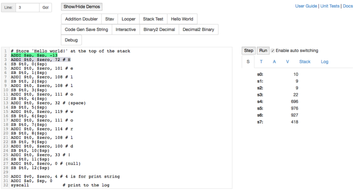
```
# Store 'Hello world!' at the top of the stack
ADDI $sp, $sp, -13
ADDI $t0, $zero, 72 # H
SB $t0, 0($sp)
ADDI $t0, $zero, 101 # e
SB $t0, 1($sp)
ADDI $t0, $zero, 108 # l
SB $t0, 2($sp)
ADDI $t0, $zero, 108 # l
SB $t0, 3($sp)
ADDI $t0, $zero, 111 # o
SB $t0, 4($sp)
ADDI $t0, $zero, 32 # (space)
SB $t0, 5($sp)
ADDI $t0, $zero, 119 # w
SB $t0, 6($sp)
ADDI $t0, $zero, 111 # o
SB $t0, 7($sp)
ADDI $t0, $zero, 114 # r
SB $t0, 8($sp)
ADDI $t0, $zero, 108 # l
SB $t0, 9($sp)
ADDI $t0, $zero, 100 # d
SB $t0, 10($sp)
ADDI $t0, $zero, 33 # !
SB $t0, 11($sp)
ADDI $t0, $zero, 0 # (null)
SB $t0, 12($sp)

ADDI $v0, $zero, 4 # 4 is for print string
ADDI $a0, $sp, 0
syscall              # print to the log
```

```
s0:   10
s1:    9
s2:    9
s3:   22
s4:  696
s5:  976
s6:  927
s7:  418
```

- **Registers:** locations for storing information that can be quickly accessed. Names start with '$': `$s0`, `$s1`, `$t0`, `$t1`,...
- **R Instructions:** Commands that use data in the registers: `add $s1, $s2, $s3` (Basic form: `OP rd, rs, rt`)
- **I Instructions:** instructions that also use intermediate values. `addi $s1, $s2, 100` (Basic form: `OP rd, rs, imm`)
- **J Instructions:** instructions that jump to another memory location.

MIPS Commands



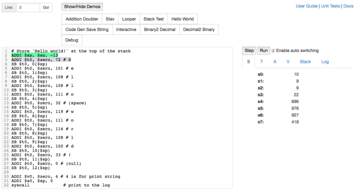
```
# Store 'Hello world!' at the top of the stack
ADDI $sp, $sp, -13
ADDI $t0, $zero, 72 # H
SB $t0, 0($sp)
ADDI $t0, $zero, 101 # e
SB $t0, 1($sp)
ADDI $t0, $zero, 108 # l
SB $t0, 2($sp)
ADDI $t0, $zero, 108 # l
SB $t0, 3($sp)
ADDI $t0, $zero, 111 # o
SB $t0, 4($sp)
ADDI $t0, $zero, 32 # (space)
SB $t0, 5($sp)
ADDI $t0, $zero, 119 # w
SB $t0, 6($sp)
ADDI $t0, $zero, 111 # o
SB $t0, 7($sp)
ADDI $t0, $zero, 114 # r
SB $t0, 8($sp)
ADDI $t0, $zero, 108 # l
SB $t0, 9($sp)
ADDI $t0, $zero, 100 # d
SB $t0, 10($sp)
ADDI $t0, $zero, 33 # !
SB $t0, 11($sp)
ADDI $t0, $zero, 0 # (null)
SB $t0, 12($sp)

ADDI $v0, $zero, 4 # 4 is for print string
ADDI $a0, $sp, 0
syscall             # print to the log
```

s0:	10
s1:	9
s2:	9
s3:	22
s4:	696
s5:	976
s6:	927
s7:	418

- **Registers:** locations for storing information that can be quickly accessed. Names start with '$': `$s0`, `$s1`, `$t0`, `$t1`,...
- **R Instructions:** Commands that use data in the registers:
  `add $s1, $s2, $s3` (Basic form: `OP rd, rs, rt`)
- **I Instructions:** instructions that also use intermediate values.
  `addi $s1, $s2, 100` (Basic form: `OP rd, rs, imm`)
- **J Instructions:** instructions that jump to another memory location.
  `j done`

MIPS Commands



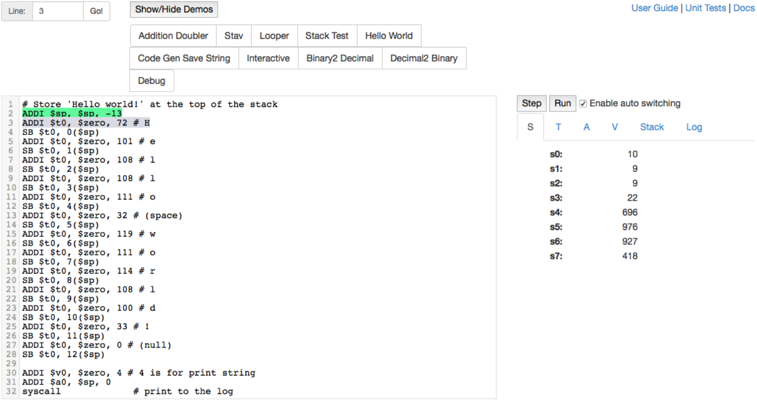
```
# Store 'Hello world!' at the top of the stack
ADDI $sp, $sp, -13
ADDI $t0, $zero, 72 # H
SB $t0, 0($sp)
ADDI $t0, $zero, 101 # e
SB $t0, 1($sp)
ADDI $t0, $zero, 108 # l
SB $t0, 2($sp)
ADDI $t0, $zero, 108 # l
SB $t0, 3($sp)
ADDI $t0, $zero, 111 # o
SB $t0, 4($sp)
ADDI $t0, $zero, 32 # (space)
SB $t0, 5($sp)
ADDI $t0, $zero, 119 # w
SB $t0, 6($sp)
ADDI $t0, $zero, 111 # o
SB $t0, 7($sp)
ADDI $t0, $zero, 114 # r
SB $t0, 8($sp)
ADDI $t0, $zero, 108 # l
SB $t0, 9($sp)
ADDI $t0, $zero, 100 # d
SB $t0, 10($sp)
ADDI $t0, $zero, 33 # !
SB $t0, 11($sp)
ADDI $t0, $zero, 0 # (null)
SB $t0, 12($sp)

ADDI $v0, $zero, 4 # 4 is for print string
ADDI $a0, $sp, 0
syscall            # print to the log
```

```
s0:    10
s1:     9
s2:     9
s3:    22
s4:   696
s5:   976
s6:   927
s7:   418
```

- **Registers:** locations for storing information that can be quickly accessed. Names start with '\$': `$s0`, `$s1`, `$t0`, `$t1`,...
- **R Instructions:** Commands that use data in the registers:
  `add $s1, $s2, $s3` (Basic form: `OP rd, rs, rt`)
- **I Instructions:** instructions that also use intermediate values.
  `addi $s1, $s2, 100` (Basic form: `OP rd, rs, imm`)
- **J Instructions:** instructions that jump to another memory location.
  `j done` (Basic form: `OP label`)

Challenge:



Line: 3

☑ Enable auto switching

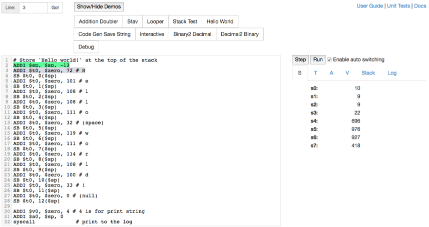
```
# Store 'Hello world!' at the top of the stack
ADDI $sp, $sp, -13
ADDI $t0, $zero, 72 # H
SB $t0, 0($sp)
ADDI $t0, $zero, 101 # e
SB $t0, 1($sp)
ADDI $t0, $zero, 108 # l
SB $t0, 2($sp)
ADDI $t0, $zero, 108 # l
SB $t0, 3($sp)
ADDI $t0, $zero, 111 # o
SB $t0, 4($sp)
ADDI $t0, $zero, 32 # (space)
SB $t0, 5($sp)
ADDI $t0, $zero, 119 # w
SB $t0, 6($sp)
ADDI $t0, $zero, 111 # o
SB $t0, 7($sp)
ADDI $t0, $zero, 114 # r
SB $t0, 8($sp)
ADDI $t0, $zero, 108 # l
SB $t0, 9($sp)
ADDI $t0, $zero, 100 # d
SB $t0, 10($sp)
ADDI $t0, $zero, 33 # !
SB $t0, 11($sp)
ADDI $t0, $zero, 0 # (null)
SB $t0, 12($sp)

ADDI $v0, $zero, 4 # 4 is for print string
ADDI $a0, $sp, 0
syscall          # print to the log
```

s0:	10
s1:	9
s2:	9
s3:	22
s4:	696
s5:	976
s6:	927
s7:	418

Write a program that prints out the alphabet: `a b c d ...  x y z`

WeMIPS



```
# Store 'Hello world!' at the top of the stack
ADDI $sp, $sp, -13
ADDI $t0, $zero, 72 # H
SB $t0, 0($sp)
ADDI $t0, $zero, 101 # e
SB $t0, 1($sp)
ADDI $t0, $zero, 108 # l
SB $t0, 2($sp)
ADDI $t0, $zero, 108 # l
SB $t0, 3($sp)
ADDI $t0, $zero, 111 # o
SB $t0, 4($sp)
ADDI $t0, $zero, 32 # (space)
SB $t0, 5($sp)
ADDI $t0, $zero, 119 # w
SB $t0, 6($sp)
ADDI $t0, $zero, 111 # o
SB $t0, 7($sp)
ADDI $t0, $zero, 114 # r
SB $t0, 8($sp)
ADDI $t0, $zero, 108 # l
SB $t0, 9($sp)
ADDI $t0, $zero, 100 # d
SB $t0, 10($sp)
ADDI $t0, $zero, 33 # !
SB $t0, 11($sp)
ADDI $t0, $zero, 0 # (null)
SB $t0, 12($sp)

ADDI $v0, $zero, 4 # 4 is for print string
ADDI $a0, $sp, 0
syscall            # print to the log
```

```
s0:    10
s1:     9
s2:     9
s3:    22
s4:   696
s5:   976
s6:   927
s7:   418
```

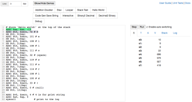
(Demo with `WeMIPS`)

Today's Topics

- Design Patterns: Searching
- Python Recap
- Machine Language
- **Machine Language: Jumps & Loops**
- Binary & Hex Arithmetic
- Final Exam: Format

Loops & Jumps in Machine Language

- Instead of built-in looping structures like `for` and `while`, you create your own loops by "jumping" to the location in the program.



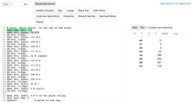
```
# Store 'Hello world!' at the top of the stack
ADDI $sp, $sp, -13
ADDI $t0, $zero, 72 # H
SB $t0, 0($sp)
ADDI $t0, $zero, 101 # e
SB $t0, 1($sp)
ADDI $t0, $zero, 108 # l
SB $t0, 2($sp)
ADDI $t0, $zero, 108 # l
SB $t0, 3($sp)
ADDI $t0, $zero, 111 # o
SB $t0, 4($sp)
ADDI $t0, $zero, 32 # (space)
SB $t0, 5($sp)
ADDI $t0, $zero, 119 # w
SB $t0, 6($sp)
ADDI $t0, $zero, 111 # o
SB $t0, 7($sp)
ADDI $t0, $zero, 114 # r
SB $t0, 8($sp)
ADDI $t0, $zero, 108 # l
SB $t0, 9($sp)
ADDI $t0, $zero, 100 # d
SB $t0, 10($sp)
ADDI $t0, $zero, 33 # !
SB $t0, 11($sp)
ADDI $t0, $zero, 0 # (null)
SB $t0, 12($sp)

ADDI $v0, $zero, 4 # 4 is for print string
ADDI $a0, $sp, 0
syscall            # print to the log
```

```
s0:    10
s1:     9
s2:     9
s3:    22
s4:   696
s5:   976
s6:   927
s7:   418
```

Loops & Jumps in Machine Language

- Instead of built-in looping structures like `for` and `while`, you create your own loops by “jumping” to the location in the program.
- Can indicate locations by writing **labels** at the beginning of a line.

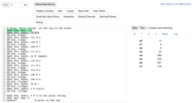


```
# Store 'Hello world!' at the top of the stack
ADDI $sp, $sp, -13
ADDI $t0, $zero, 72 # H
SB $t0, 0($sp)
ADDI $t0, $zero, 101 # e
SB $t0, 1($sp)
ADDI $t0, $zero, 108 # l
SB $t0, 2($sp)
ADDI $t0, $zero, 108 # l
SB $t0, 3($sp)
ADDI $t0, $zero, 111 # o
SB $t0, 4($sp)
ADDI $t0, $zero, 32 # (space)
SB $t0, 5($sp)
ADDI $t0, $zero, 119 # w
SB $t0, 6($sp)
ADDI $t0, $zero, 111 # o
SB $t0, 7($sp)
ADDI $t0, $zero, 114 # r
SB $t0, 8($sp)
ADDI $t0, $zero, 108 # l
SB $t0, 9($sp)
ADDI $t0, $zero, 100 # d
SB $t0, 10($sp)
ADDI $t0, $zero, 33 # !
SB $t0, 11($sp)
ADDI $t0, $zero, 0 # (null)
SB $t0, 12($sp)

ADDI $v0, $zero, 4 # 4 is for print string
ADDI $a0, $sp, 0
syscall          # print to the log
```

```
s0:  10
s1:   8
s2:   9
s3:  22
s4: 686
s5: 976
s6: 927
s7: 418
```

Loops & Jumps in Machine Language



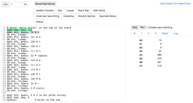
```
# Store 'Hello world!' at the top of the stack
ADDI $sp, $sp, -13
ADDI $t0, $zero, 72 # H
SB $t0, 0($sp)
ADDI $t0, $zero, 101 # e
SB $t0, 1($sp)
ADDI $t0, $zero, 108 # l
SB $t0, 2($sp)
ADDI $t0, $zero, 108 # l
SB $t0, 3($sp)
ADDI $t0, $zero, 111 # o
SB $t0, 4($sp)
ADDI $t0, $zero, 32 # (space)
SB $t0, 5($sp)
ADDI $t0, $zero, 119 # w
SB $t0, 6($sp)
ADDI $t0, $zero, 111 # o
SB $t0, 7($sp)
ADDI $t0, $zero, 114 # r
SB $t0, 8($sp)
ADDI $t0, $zero, 108 # l
SB $t0, 9($sp)
ADDI $t0, $zero, 100 # d
SB $t0, 10($sp)
ADDI $t0, $zero, 33 # !
SB $t0, 11($sp)
ADDI $t0, $zero, 0 # (null)
SB $t0, 12($sp)

ADDI $v0, $zero, 4 # 4 is for print string
ADDI $a0, $sp, 0
syscall             # print to the log
```

```
s0:   10
s1:    8
s2:    9
s3:   22
s4:  686
s5:  976
s6:  927
s7:  418
```

- Instead of built-in looping structures like `for` and `while`, you create your own loops by "jumping" to the location in the program.
- Can indicate locations by writing **labels** at the beginning of a line.
- Then give a command to jump to that location.

Loops & Jumps in Machine Language



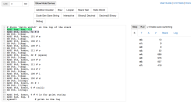
```
# Store 'Hello world!' at the top of the stack
ADDI $sp, $sp, -13
ADDI $t0, $zero, 72 # H
SB $t0, 0($sp)
ADDI $t0, $zero, 101 # e
SB $t0, 1($sp)
ADDI $t0, $zero, 108 # l
SB $t0, 2($sp)
ADDI $t0, $zero, 108 # l
SB $t0, 3($sp)
ADDI $t0, $zero, 111 # o
SB $t0, 4($sp)
ADDI $t0, $zero, 32 # (space)
SB $t0, 5($sp)
ADDI $t0, $zero, 119 # w
SB $t0, 6($sp)
ADDI $t0, $zero, 111 # o
SB $t0, 7($sp)
ADDI $t0, $zero, 114 # r
SB $t0, 8($sp)
ADDI $t0, $zero, 108 # l
SB $t0, 9($sp)
ADDI $t0, $zero, 100 # d
SB $t0, 10($sp)
ADDI $t0, $zero, 33 # !
SB $t0, 11($sp)
ADDI $t0, $zero, 0 # (null)
SB $t0, 12($sp)

ADDI $v0, $zero, 4 # 4 is for print string
ADDI $a0, $sp, 0
syscall          # print to the log
```

```
s0:   10
s1:    8
s2:    9
s3:   22
s4:  686
s5:  976
s6:  927
s7:  418
```

- Instead of built-in looping structures like `for` and `while`, you create your own loops by "jumping" to the location in the program.
- Can indicate locations by writing **labels** at the beginning of a line.
- Then give a command to jump to that location.
- Different kinds of jumps:

Loops & Jumps in Machine Language



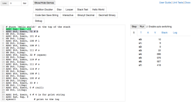
```
# Store 'Hello world!' at the top of the stack
ADDI $sp, $sp, -13
ADDI $t0, $zero, 72 # H
SB $t0, 0($sp)
ADDI $t0, $zero, 101 # e
SB $t0, 1($sp)
ADDI $t0, $zero, 108 # l
SB $t0, 2($sp)
ADDI $t0, $zero, 108 # l
SB $t0, 3($sp)
ADDI $t0, $zero, 111 # o
SB $t0, 4($sp)
ADDI $t0, $zero, 32 # (space)
SB $t0, 5($sp)
ADDI $t0, $zero, 119 # w
SB $t0, 6($sp)
ADDI $t0, $zero, 111 # o
SB $t0, 7($sp)
ADDI $t0, $zero, 114 # r
SB $t0, 8($sp)
ADDI $t0, $zero, 108 # l
SB $t0, 9($sp)
ADDI $t0, $zero, 100 # d
SB $t0, 10($sp)
ADDI $t0, $zero, 33 # !
SB $t0, 11($sp)
ADDI $t0, $zero, 0 # (null)
SB $t0, 12($sp)

ADDI $v0, $zero, 4 # 4 is for print string
ADDI $a0, $sp, 0
syscall            # print to the log
```

```
s0:   10
s1:    9
s2:    9
s3:   22
s4:  686
s5:  976
s6:  927
s7:  418
```

- Instead of built-in looping structures like `for` and `while`, you create your own loops by “jumping” to the location in the program.
- Can indicate locations by writing **labels** at the beginning of a line.
- Then give a command to jump to that location.
- Different kinds of jumps:
  - **Unconditional:** `j Done` will jump to the address with label `Done`.

Loops & Jumps in Machine Language



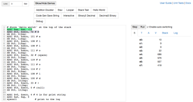
```
# Store 'Hello world!' at the top of the stack
ADDI $sp, $sp, -13
ADDI $t0, $zero, 72 # H
SB $t0, 0($sp)
ADDI $t0, $zero, 101 # e
SB $t0, 1($sp)
ADDI $t0, $zero, 108 # l
SB $t0, 2($sp)
ADDI $t0, $zero, 108 # l
SB $t0, 3($sp)
ADDI $t0, $zero, 111 # o
SB $t0, 4($sp)
ADDI $t0, $zero, 32 # (space)
SB $t0, 5($sp)
ADDI $t0, $zero, 119 # w
SB $t0, 6($sp)
ADDI $t0, $zero, 111 # o
SB $t0, 7($sp)
ADDI $t0, $zero, 114 # r
SB $t0, 8($sp)
ADDI $t0, $zero, 108 # l
SB $t0, 9($sp)
ADDI $t0, $zero, 100 # d
SB $t0, 10($sp)
ADDI $t0, $zero, 33 # !
SB $t0, 11($sp)
ADDI $t0, $zero, 0 # (null)
SB $t0, 12($sp)

ADDI $v0, $zero, 4 # 4 is for print string
ADDI $a0, $sp, 0
syscall            # print to the log
```

s0:	10
s1:	9
s2:	9
s3:	22
s4:	686
s5:	976
s6:	927
s7:	418

- Instead of built-in looping structures like `for` and `while`, you create your own loops by "jumping" to the location in the program.
- Can indicate locations by writing **labels** at the beginning of a line.
- Then give a command to jump to that location.
- Different kinds of jumps:
    - **Unconditional:** `j Done` will jump to the address with label `Done`.
    - **Branch if Equal:** `beq $s0 $s1 DoAgain` will jump to the address with label `DoAgain` if the registers $s0 and $s1 contain the same value.

Loops & Jumps in Machine Language



```
# Store 'Hello world!' at the top of the stack
ADDI $sp, $sp, -13
ADDI $t0, $zero, 72 # H
SB $t0, 0($sp)
ADDI $t0, $zero, 101 # e
SB $t0, 1($sp)
ADDI $t0, $zero, 108 # l
SB $t0, 2($sp)
ADDI $t0, $zero, 108 # l
SB $t0, 3($sp)
ADDI $t0, $zero, 111 # o
SB $t0, 4($sp)
ADDI $t0, $zero, 32 # (space)
SB $t0, 5($sp)
ADDI $t0, $zero, 119 # w
SB $t0, 6($sp)
ADDI $t0, $zero, 111 # o
SB $t0, 7($sp)
ADDI $t0, $zero, 114 # r
SB $t0, 8($sp)
ADDI $t0, $zero, 108 # l
SB $t0, 9($sp)
ADDI $t0, $zero, 100 # d
SB $t0, 10($sp)
ADDI $t0, $zero, 33 # !
SB $t0, 11($sp)
ADDI $t0, $zero, 0 # (null)
SB $t0, 12($sp)

ADDI $v0, $zero, 4 # 4 is for print string
ADDI $a0, $sp, 0
syscall            # print to the log
```

```
s0:   10
s1:    9
s2:    9
s3:   22
s4:  686
s5:  976
s6:  927
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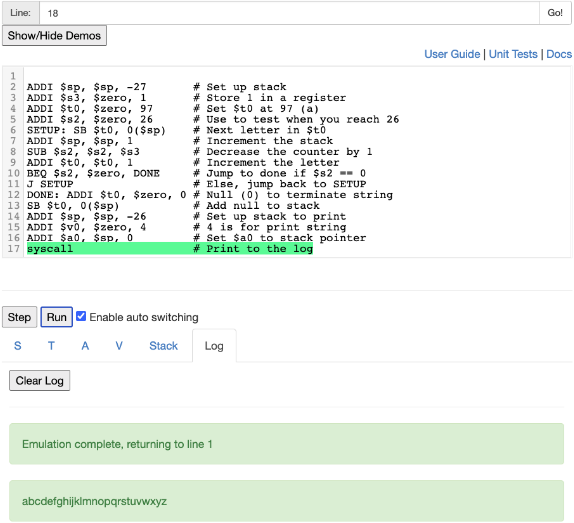
```

- Instead of built-in looping structures like `for` and `while`, you create your own loops by "jumping" to the location in the program.
- Can indicate locations by writing **labels** at the beginning of a line.
- Then give a command to jump to that location.
- Different kinds of jumps:
  - **Unconditional:** `j Done` will jump to the address with label `Done`.
  - **Branch if Equal:** `beq $s0 $s1 DoAgain` will jump to the address with label `DoAgain` if the registers $s0 and $s1 contain the same value.
  - See reading for more variations.

Jump Demo



```
ADDI $sp, $sp, -27       # Set up stack
ADDI $s3, $zero, 1       # Store 1 in a register
ADDI $t0, $zero, 97      # Set $t0 at 97 (a)
ADDI $s2, $zero, 26      # Use to test when you reach 26
SETUP: SB $t0, 0($sp)    # Next letter in $t0
ADDI $sp, $sp, 1         # Increment the stack
SUB $s2, $s2, $s3        # Decrease the counter by 1
ADDI $t0, $t0, 1         # Increment the letter
BEQ $s2, $zero, DONE     # Jump to done if $s2 == 0
J SETUP                  # Else, jump back to SETUP
DONE: ADDI $t0, $zero, 0 # Null (0) to terminate string
SB $t0, 0($sp)           # Add null to stack
ADDI $sp, $sp, -26       # Set up stack to print
ADDI $v0, $zero, 4       # 4 is for print string
ADDI $a0, $sp, 0         # Set $a0 to stack pointer
syscall                  # Print to the log
```

```
Emulation complete, returning to line 1
```

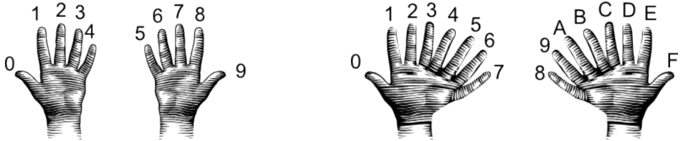
```
abcdefghijklmnopqrstuvwxyz
```

(Demo with WeMIPS)

Today's Topics

- Design Patterns: Searching
- Python Recap
- Machine Language
- Machine Language: Jumps & Loops
- **Binary & Hex Arithmetic**
- Final Exam: Format

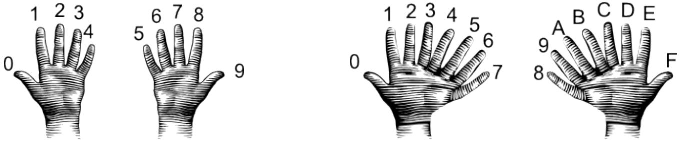
Hexadecimal to Decimal: Converting Between Bases



(from i-programmer.info)

- From hexadecimal to decimal (assuming two-digit numbers):
    - Convert first digit to decimal and multiple by 16.

Hexadecimal to Decimal: Converting Between Bases



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- From hexadecimal to decimal (assuming two-digit numbers):
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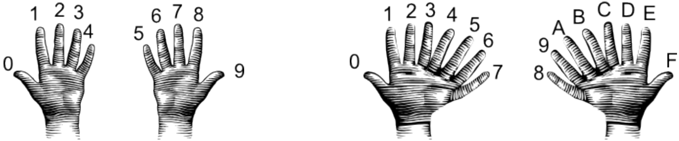
  - Convert second digit to decimal and add to total.

Hexadecimal to Decimal: Converting Between Bases



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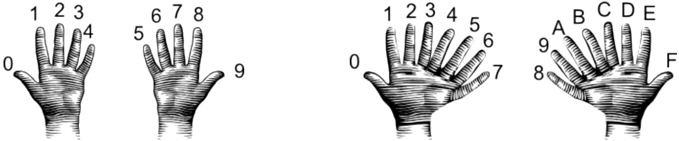
- From hexadecimal to decimal (assuming two-digit numbers):
  - Convert first digit to decimal and multiple by 16.
  - Convert second digit to decimal and add to total.
  - Example: what is 2A as a decimal number?

Hexadecimal to Decimal: Converting Between Bases



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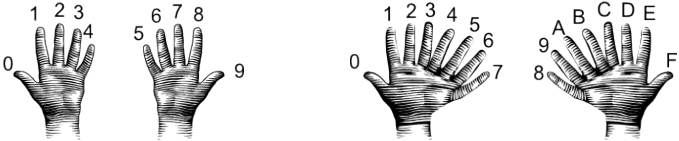
- From hexadecimal to decimal (assuming two-digit numbers):
  - Convert first digit to decimal and multiple by 16.
  - Convert second digit to decimal and add to total.
  - Example: what is 2A as a decimal number?

    `2 in decimal is 2.`

Hexadecimal to Decimal: Converting Between Bases



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  - Convert first digit to decimal and multiple by 16.
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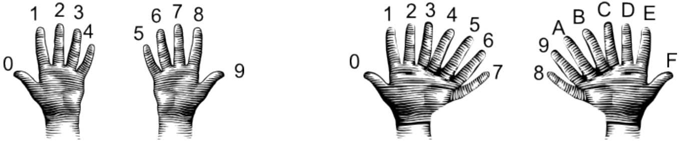
    ```
    2 in decimal is 2. 2*16 is 32.
    ```

Hexadecimal to Decimal: Converting Between Bases



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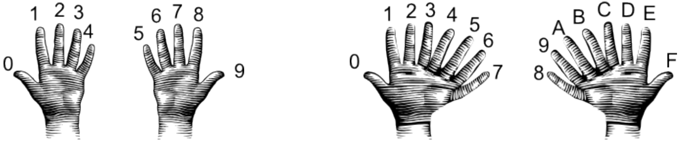
  - Example: what is 2A as a decimal number?

```
2 in decimal is 2. 2*16 is 32.
A in decimal digits is 10.
```

Hexadecimal to Decimal: Converting Between Bases



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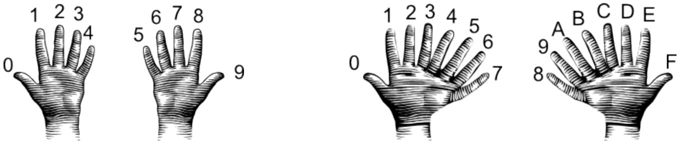
- From hexadecimal to decimal (assuming two-digit numbers):
  - Convert first digit to decimal and multiple by 16.
  - Convert second digit to decimal and add to total.
  - Example: what is 2A as a decimal number?

    ```
    2 in decimal is 2. 2*16 is 32.
    A in decimal digits is 10.
    32 + 10 is 42.
    ```

Hexadecimal to Decimal: Converting Between Bases



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- From hexadecimal to decimal (assuming two-digit numbers):
    - Convert first digit to decimal and multiple by 16.
    - Convert second digit to decimal and add to total.
    - Example: what is 2A as a decimal number?

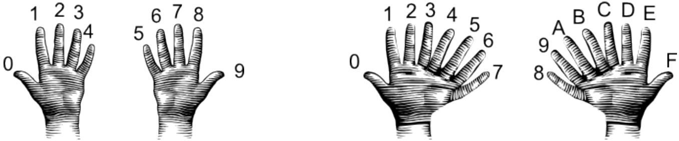
      2 in decimal is 2. 2*16 is 32.

      A in decimal digits is 10.

      32 + 10 is 42.

      Answer is 42.
    - Example: what is 99 as a decimal number?

Hexadecimal to Decimal: Converting Between Bases



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- From hexadecimal to decimal (assuming two-digit numbers):
  - Convert first digit to decimal and multiple by 16.
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  - Example: what is 2A as a decimal number?

    `2 in decimal is 2. 2*16 is 32.`

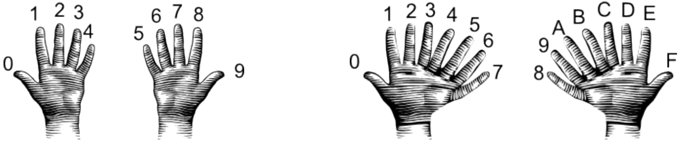
    `A in decimal digits is 10.`

    `32 + 10 is 42.`

    Answer is 42.
  - Example: what is 99 as a decimal number?

    `9 in decimal is 9.`

Hexadecimal to Decimal: Converting Between Bases



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- From hexadecimal to decimal (assuming two-digit numbers):
  - Convert first digit to decimal and multiple by 16.
  - Convert second digit to decimal and add to total.
  - Example: what is 2A as a decimal number?

    2 in decimal is 2. 2*16 is 32.

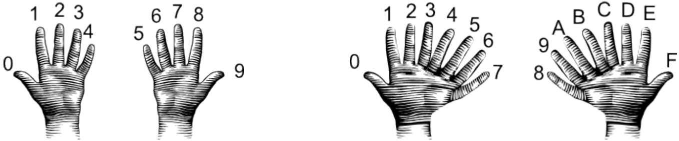
    A in decimal digits is 10.

    32 + 10 is 42.

    Answer is 42.
  - Example: what is 99 as a decimal number?

    9 in decimal is 9. 9*16 is 144.

Hexadecimal to Decimal: Converting Between Bases



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  - Example: what is 2A as a decimal number?

    ```
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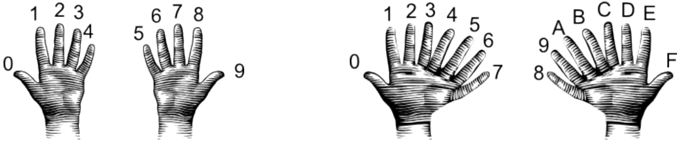
    A in decimal digits is 10.
    32 + 10 is 42.
    ```

    Answer is 42.
  - Example: what is 99 as a decimal number?

    ```
    9 in decimal is 9. 9*16 is 144.
    9 in decimal digits is 9
    ```

Hexadecimal to Decimal: Converting Between Bases



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    `2 in decimal is 2. 2*16 is 32.`

    `A in decimal digits is 10.`

    `32 + 10 is 42.`

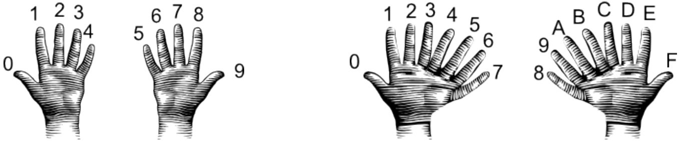
    Answer is 42.
  - Example: what is 99 as a decimal number?

    `9 in decimal is 9. 9*16 is 144.`

    `9 in decimal digits is 9`

    `144 + 9 is 153.`

Hexadecimal to Decimal: Converting Between Bases



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  - Example: what is 2A as a decimal number?

    `2 in decimal is 2. 2*16 is 32.`

    `A in decimal digits is 10.`

    `32 + 10 is 42.`

    Answer is 42.
  - Example: what is 99 as a decimal number?

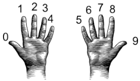
    `9 in decimal is 9. 9*16 is 144.`

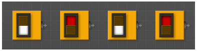
    `9 in decimal digits is 9`

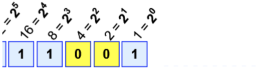
    `144 + 9 is 153.`

    Answer is 153.

Decimal to Binary: Converting Between Bases



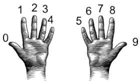


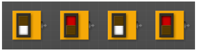


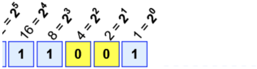
Example: 1×16 + 1×8 + 1×1 = 16+8+1 = 25

- From decimal to binary:
  - Divide by 128 ($= 2^7$). Quotient is the first digit.

Decimal to Binary: Converting Between Bases



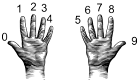


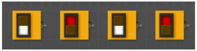


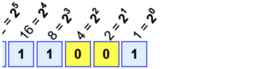
Example: 1×16 + 1×8 + 1×1 = 16+8+1 = 25

- From decimal to binary:
  - Divide by 128 ($= 2^7$). Quotient is the first digit.
  - Divide remainder by 64 ($= 2^6$). Quotient is the next digit.

Decimal to Binary: Converting Between Bases







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  - Divide by 128 ($= 2^7$). Quotient is the first digit.
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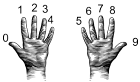
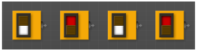
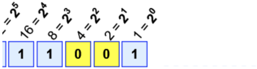
  - Divide remainder by 32 ($= 2^5$). Quotient is the next digit.

Decimal to Binary: Converting Between Bases







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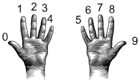
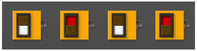
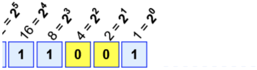
  - Divide remainder by 16 ($= 2^4$). Quotient is the next digit.

Decimal to Binary: Converting Between Bases







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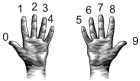
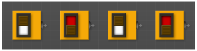
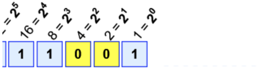
- From decimal to binary:
  - Divide by 128 ($= 2^7$). Quotient is the first digit.
  - Divide remainder by 64 ($= 2^6$). Quotient is the next digit.
  - Divide remainder by 32 ($= 2^5$). Quotient is the next digit.
  - Divide remainder by 16 ($= 2^4$). Quotient is the next digit.
  - Divide remainder by 8 ($= 2^3$). Quotient is the next digit.

Decimal to Binary: Converting Between Bases







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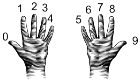

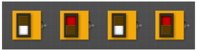

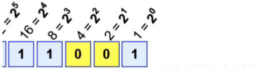

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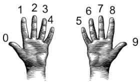

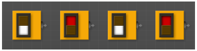

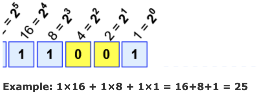

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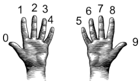

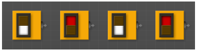

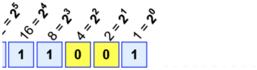

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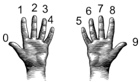
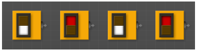
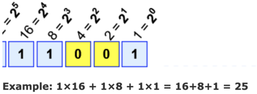
Decimal to Binary: Converting Between Bases







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130/128 is 1 rem 2.
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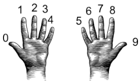

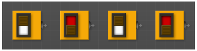

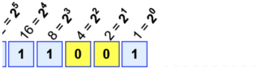

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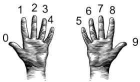

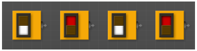

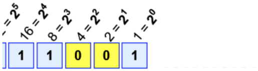

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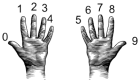

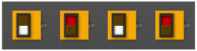

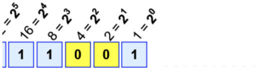

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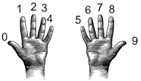

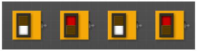

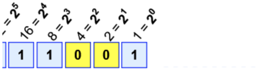

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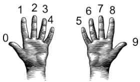

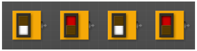

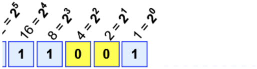

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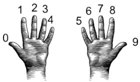

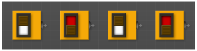

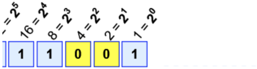

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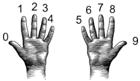

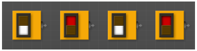

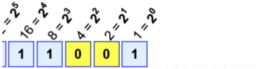

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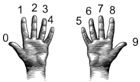

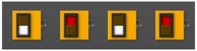

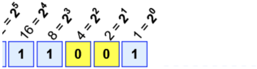

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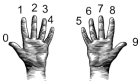

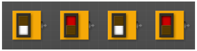

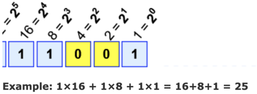

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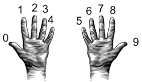

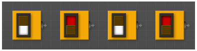

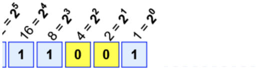

Example: 1×16 + 1×8 + 1×1 = 16+8+1 = 25

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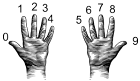
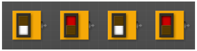
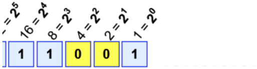
Decimal to Binary: Converting Between Bases







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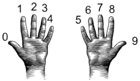

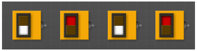

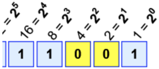

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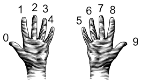

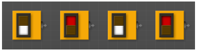

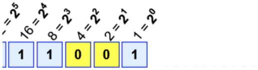

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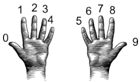

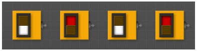

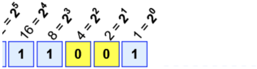

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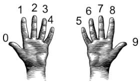
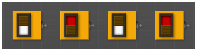
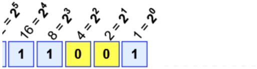
Decimal to Binary: Converting Between Bases







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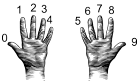
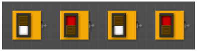
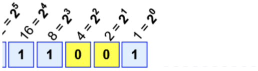
Decimal to Binary: Converting Between Bases







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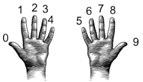
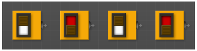
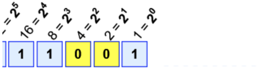
Decimal to Binary: Converting Between Bases







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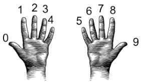
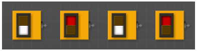
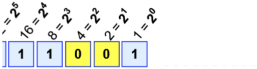
Decimal to Binary: Converting Between Bases







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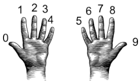
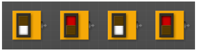
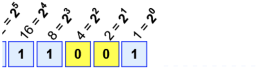
Decimal to Binary: Converting Between Bases







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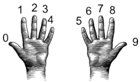

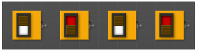

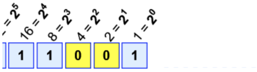

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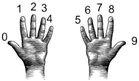
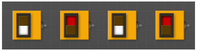
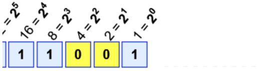
Adding the last remainder:               10000010
```

Decimal to Binary: Converting Between Bases







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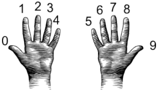
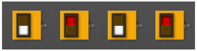
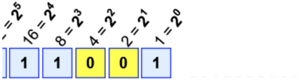


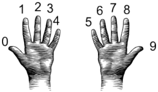


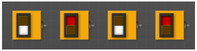


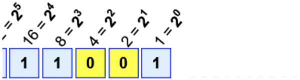
Example: 1×16 + 1×8 + 1×1 = 16+8+1 = 25

- Example: what is 99 in binary notation?

Decimal to Binary: Converting Between Bases







Example: 1×16 + 1×8 + 1×1 = 16+8+1 = 25

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99/128 is 0 rem 99.
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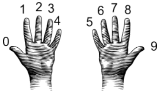

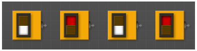

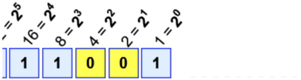

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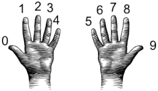

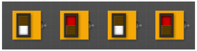

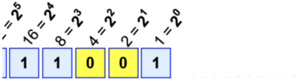

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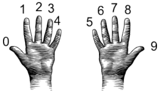

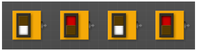

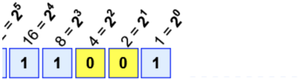

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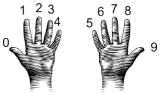

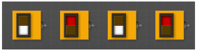

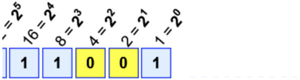

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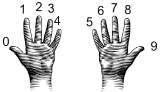

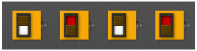

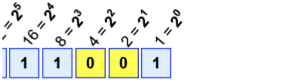

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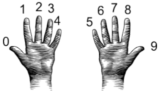

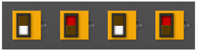

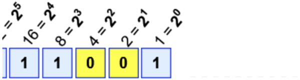

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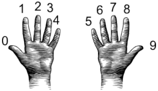

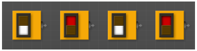

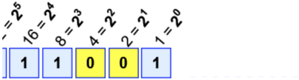

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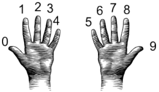

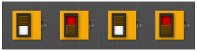

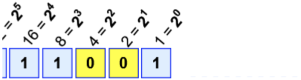

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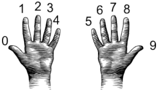

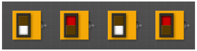

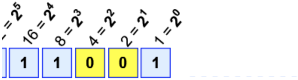

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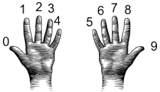

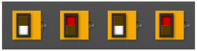

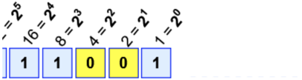

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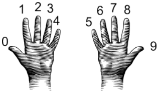

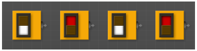

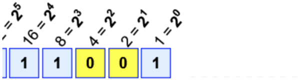

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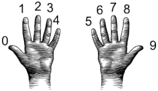

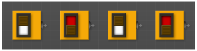

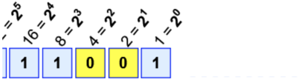

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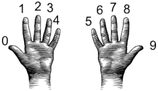

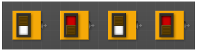

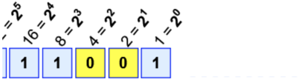

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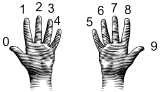

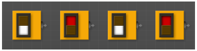

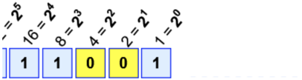

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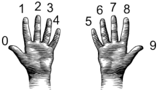

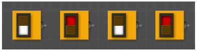

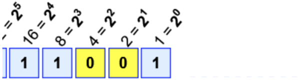

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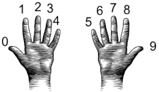

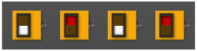

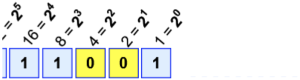

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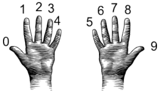

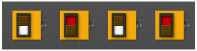

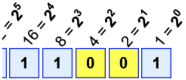

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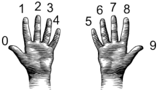

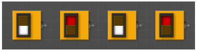

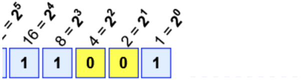

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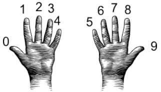
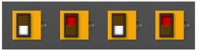
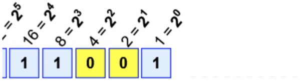
3/4 is 0 remainder 3. Next digit is 0:   011000...
3/2 is 1 rem 1. Next digit is 1:
```

Decimal to Binary: Converting Between Bases





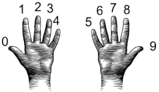


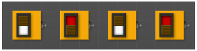
Example: 1×16 + 1×8 + 1×1 = 16+8+1 = 25

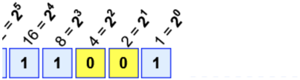
- Example: what is 99 in binary notation?

```
99/128 is 0 rem 99. First digit is 0:     0...
99/64 is 1 rem 35. Next digit is 1:       01...
35/32 is 1 rem 3. Next digit is 1:        011...
3/16 is 0 rem 3. Next digit is 0:         0110...
3/8 is 0 rem 3. Next digit is 0:          01100...
3/4 is 0 remainder 3. Next digit is 0:    011000...
3/2 is 1 rem 1. Next digit is 1:          0110001...
```

Decimal to Binary: Converting Between Bases





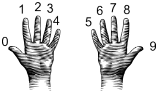


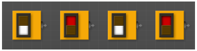
Example: 1×16 + 1×8 + 1×1 = 16+8+1 = 25

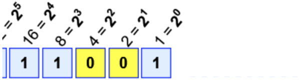
- Example: what is 99 in binary notation?

```
99/128 is 0 rem 99. First digit is 0:       0...
99/64 is 1 rem 35. Next digit is 1:         01...
35/32 is 1 rem 3. Next digit is 1:          011...
3/16 is 0 rem 3. Next digit is 0:           0110...
3/8 is 0 rem 3. Next digit is 0:            01100...
3/4 is 0 remainder 3. Next digit is 0:      011000...
3/2 is 1 rem 1. Next digit is 1:            0110001...
Adding the last remainder:                  01100011
```

Decimal to Binary: Converting Between Bases







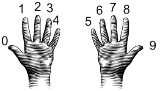
Example: 1×16 + 1×8 + 1×1 = 16+8+1 = 25

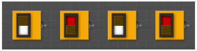
- Example: what is 99 in binary notation?

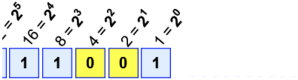
```
99/128 is 0 rem 99. First digit is 0:    0...
99/64 is 1 rem 35. Next digit is 1:      01...
35/32 is 1 rem 3. Next digit is 1:       011...
3/16 is 0 rem 3. Next digit is 0:        0110...
3/8 is 0 rem 3. Next digit is 0:         01100...
3/4 is 0 remainder 3. Next digit is 0:   011000...
3/2 is 1 rem 1. Next digit is 1:         0110001...
Adding the last remainder:               01100011
```

Answer is 1100011.

Binary to Decimal: Converting Between Bases



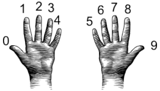


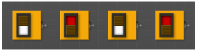


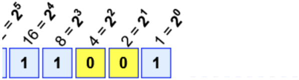
Example: 1×16 + 1×8 + 1×1 = 16+8+1 = 25

- From binary to decimal:
  - Set sum = last digit.

Binary to Decimal: Converting Between Bases



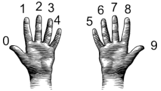


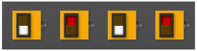


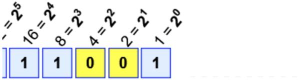
Example: 1×16 + 1×8 + 1×1 = 16+8+1 = 25

- From binary to decimal:
  - Set sum = last digit.
  - Multiply next digit by $2 = 2^1$. Add to sum.

Binary to Decimal: Converting Between Bases



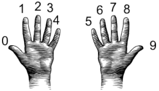


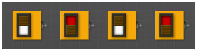


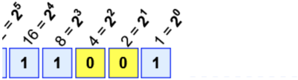
Example: 1×16 + 1×8 + 1×1 = 16+8+1 = 25

- From binary to decimal:
  - Set sum = last digit.
  - Multiply next digit by $2 = 2^1$. Add to sum.
  - Multiply next digit by $4 = 2^2$. Add to sum.

Binary to Decimal: Converting Between Bases



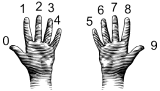


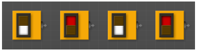


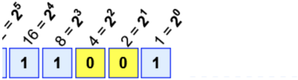
Example: 1×16 + 1×8 + 1×1 = 16+8+1 = 25

- From binary to decimal:
  - Set sum $=$ last digit.
  - Multiply next digit by $2 = 2^1$. Add to sum.
  - Multiply next digit by $4 = 2^2$. Add to sum.
  - Multiply next digit by $8 = 2^3$. Add to sum.

Binary to Decimal: Converting Between Bases



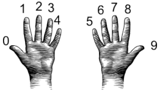


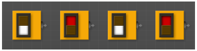


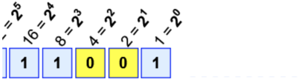
Example: 1×16 + 1×8 + 1×1 = 16+8+1 = 25

- From binary to decimal:
  - Set sum = last digit.
  - Multiply next digit by $2 = 2^1$. Add to sum.
  - Multiply next digit by $4 = 2^2$. Add to sum.
  - Multiply next digit by $8 = 2^3$. Add to sum.
  - Multiply next digit by $16 = 2^4$. Add to sum.

Binary to Decimal: Converting Between Bases







Example: 1×16 + 1×8 + 1×1 = 16+8+1 = 25

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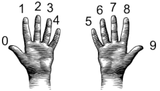
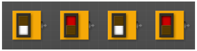
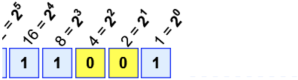
  - Set sum = last digit.
  - Multiply next digit by $2 = 2^1$. Add to sum.
  - Multiply next digit by $4 = 2^2$. Add to sum.
  - Multiply next digit by $8 = 2^3$. Add to sum.
  - Multiply next digit by $16 = 2^4$. Add to sum.
  - Multiply next digit by $32 = 2^5$. Add to sum.

Binary to Decimal: Converting Between Bases



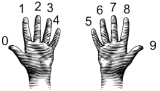


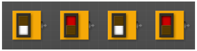


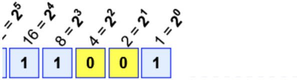
Example: 1×16 + 1×8 + 1×1 = 16+8+1 = 25

- From binary to decimal:
  - Set sum = last digit.
  - Multiply next digit by $2 = 2^1$. Add to sum.
  - Multiply next digit by $4 = 2^2$. Add to sum.
  - Multiply next digit by $8 = 2^3$. Add to sum.
  - Multiply next digit by $16 = 2^4$. Add to sum.
  - Multiply next digit by $32 = 2^5$. Add to sum.
  - Multiply next digit by $64 = 2^6$. Add to sum.

Binary to Decimal: Converting Between Bases







Example: 1×16 + 1×8 + 1×1 = 16+8+1 = 25

- From binary to decimal:
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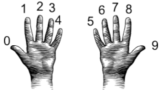
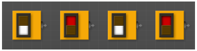
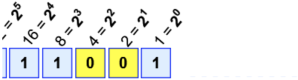
  - Multiply next digit by $8 = 2^3$. Add to sum.
  - Multiply next digit by $16 = 2^4$. Add to sum.
  - Multiply next digit by $32 = 2^5$. Add to sum.
  - Multiply next digit by $64 = 2^6$. Add to sum.
  - Multiply next digit by $128 = 2^7$. Add to sum.

Binary to Decimal: Converting Between Bases



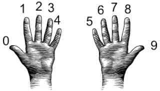


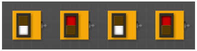


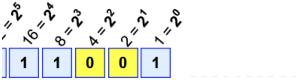
Example: 1×16 + 1×8 + 1×1 = 16+8+1 = 25

- From binary to decimal:
  - Set sum = last digit.
  - Multiply next digit by $2 = 2^1$. Add to sum.
  - Multiply next digit by $4 = 2^2$. Add to sum.
  - Multiply next digit by $8 = 2^3$. Add to sum.
  - Multiply next digit by $16 = 2^4$. Add to sum.
  - Multiply next digit by $32 = 2^5$. Add to sum.
  - Multiply next digit by $64 = 2^6$. Add to sum.
  - Multiply next digit by $128 = 2^7$. Add to sum.
  - Sum is the decimal number.

Binary to Decimal: Converting Between Bases







Example: 1×16 + 1×8 + 1×1 = 16+8+1 = 25

- From binary to decimal:
  - Set sum = last digit.
  - Multiply next digit by $2 = 2^1$. Add to sum.
  - Multiply next digit by $4 = 2^2$. Add to sum.
  - Multiply next digit by $8 = 2^3$. Add to sum.
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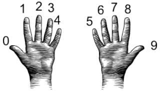
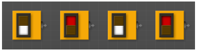
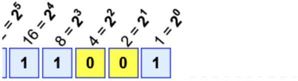
  - Multiply next digit by $32 = 2^5$. Add to sum.
  - Multiply next digit by $64 = 2^6$. Add to sum.
  - Multiply next digit by $128 = 2^7$. Add to sum.
  - Sum is the decimal number.
  - Example: What is 111101 in decimal?

```
Sum starts with:
```

Binary to Decimal: Converting Between Bases







Example: 1×16 + 1×8 + 1×1 = 16+8+1 = 25

- From binary to decimal:
  - Set sum = last digit.
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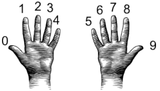
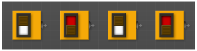
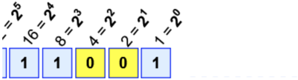
  - Multiply next digit by $128 = 2^7$. Add to sum.
  - Sum is the decimal number.
  - Example: What is 111101 in decimal?

```
Sum starts with:            1
0*2 = 0.  Add 0 to sum:
```

Binary to Decimal: Converting Between Bases







Example: 1×16 + 1×8 + 1×1 = 16+8+1 = 25

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  - Set sum = last digit.
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  - Multiply next digit by $16 = 2^4$. Add to sum.
  - Multiply next digit by $32 = 2^5$. Add to sum.
  - Multiply next digit by $64 = 2^6$. Add to sum.
  - Multiply next digit by $128 = 2^7$. Add to sum.
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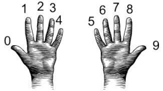
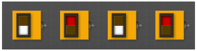
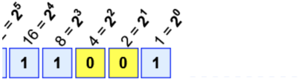
```
Sum starts with:            1
0*2 = 0.  Add 0 to sum:     1
```

Binary to Decimal: Converting Between Bases







Example: 1×16 + 1×8 + 1×1 = 16+8+1 = 25

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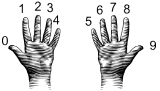
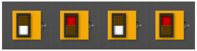
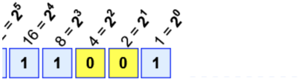
  - Multiply next digit by $64 = 2^6$. Add to sum.
  - Multiply next digit by $128 = 2^7$. Add to sum.
  - Sum is the decimal number.
  - Example: What is 111101 in decimal?

```
Sum starts with:              1
0*2 = 0.  Add 0 to sum:       1
1*4 = 4.  Add 4 to sum:
```

Binary to Decimal: Converting Between Bases







Example: 1×16 + 1×8 + 1×1 = 16+8+1 = 25

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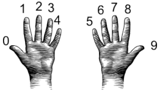
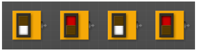
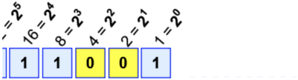
  - Multiply next digit by $2 = 2^1$. Add to sum.
  - Multiply next digit by $4 = 2^2$. Add to sum.
  - Multiply next digit by $8 = 2^3$. Add to sum.
  - Multiply next digit by $16 = 2^4$. Add to sum.
  - Multiply next digit by $32 = 2^5$. Add to sum.
  - Multiply next digit by $64 = 2^6$. Add to sum.
  - Multiply next digit by $128 = 2^7$. Add to sum.
  - Sum is the decimal number.
  - Example: What is 111101 in decimal?

```
Sum starts with:            1
0*2 = 0.   Add 0 to sum:    1
1*4 = 4.   Add 4 to sum:    5
```

Binary to Decimal: Converting Between Bases





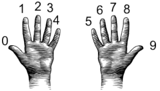


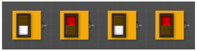
Example: 1×16 + 1×8 + 1×1 = 16+8+1 = 25

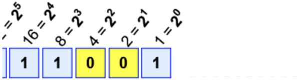
- From binary to decimal:
  - Set sum = last digit.
  - Multiply next digit by $2 = 2^1$. Add to sum.
  - Multiply next digit by $4 = 2^2$. Add to sum.
  - Multiply next digit by $8 = 2^3$. Add to sum.
  - Multiply next digit by $16 = 2^4$. Add to sum.
  - Multiply next digit by $32 = 2^5$. Add to sum.
  - Multiply next digit by $64 = 2^6$. Add to sum.
  - Multiply next digit by $128 = 2^7$. Add to sum.
  - Sum is the decimal number.
  - Example: What is 111101 in decimal?

```
Sum starts with:            1
0*2 = 0.  Add 0 to sum:     1
1*4 = 4.  Add 4 to sum:     5
1*8 = 8.  Add 8 to sum:
```

Binary to Decimal: Converting Between Bases







Example: 1×16 + 1×8 + 1×1 = 16+8+1 = 25

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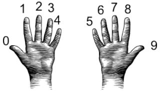
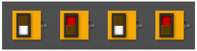
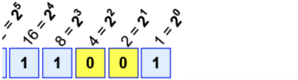
  - Multiply next digit by $64 = 2^6$. Add to sum.
  - Multiply next digit by $128 = 2^7$. Add to sum.
  - Sum is the decimal number.
  - Example: What is 111101 in decimal?

```
Sum starts with:          1
0*2 = 0.  Add 0 to sum:   1
1*4 = 4.  Add 4 to sum:   5
1*8 = 8.  Add 8 to sum:   13
```

Binary to Decimal: Converting Between Bases







Example: 1×16 + 1×8 + 1×1 = 16+8+1 = 25

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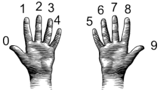
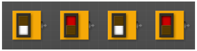
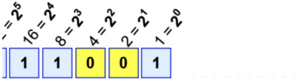
  - Multiply next digit by $32 = 2^5$. Add to sum.
  - Multiply next digit by $64 = 2^6$. Add to sum.
  - Multiply next digit by $128 = 2^7$. Add to sum.
  - Sum is the decimal number.
  - Example: What is 111101 in decimal?

```
Sum starts with:            1
0*2 = 0.  Add 0 to sum:     1
1*4 = 4.  Add 4 to sum:     5
1*8 = 8.  Add 8 to sum:     13
1*16 = 16.  Add 16 to sum:
```

Binary to Decimal: Converting Between Bases







Example: 1×16 + 1×8 + 1×1 = 16+8+1 = 25

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  - Set sum = last digit.
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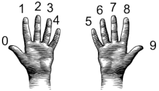
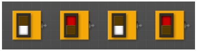
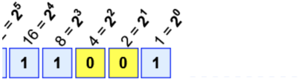
  - Multiply next digit by $16 = 2^4$. Add to sum.
  - Multiply next digit by $32 = 2^5$. Add to sum.
  - Multiply next digit by $64 = 2^6$. Add to sum.
  - Multiply next digit by $128 = 2^7$. Add to sum.
  - Sum is the decimal number.
  - Example: What is 111101 in decimal?

```
Sum starts with:             1
0*2 = 0.  Add 0 to sum:      1
1*4 = 4.  Add 4 to sum:      5
1*8 = 8.  Add 8 to sum:      13
1*16 = 16.  Add 16 to sum:   29
```

Binary to Decimal: Converting Between Bases







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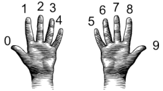
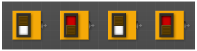
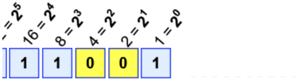
  - Multiply next digit by $8 = 2^3$. Add to sum.
  - Multiply next digit by $16 = 2^4$. Add to sum.
  - Multiply next digit by $32 = 2^5$. Add to sum.
  - Multiply next digit by $64 = 2^6$. Add to sum.
  - Multiply next digit by $128 = 2^7$. Add to sum.
  - Sum is the decimal number.
  - Example: What is 111101 in decimal?

```
Sum starts with:            1
0*2 = 0.   Add 0 to sum:    1
1*4 = 4.   Add 4 to sum:    5
1*8 = 8.   Add 8 to sum:    13
1*16 = 16.  Add 16 to sum:  29
1*32 = 32.  Add 32 to sum:
```

Binary to Decimal: Converting Between Bases







Example: 1×16 + 1×8 + 1×1 = 16+8+1 = 25

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  - Set sum = last digit.
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  - Multiply next digit by $16 = 2^4$. Add to sum.
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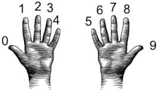
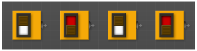
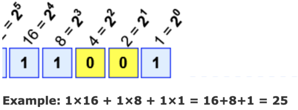
  - Multiply next digit by $64 = 2^6$. Add to sum.
  - Multiply next digit by $128 = 2^7$. Add to sum.
  - Sum is the decimal number.
  - Example: What is 111101 in decimal?

```
Sum starts with:            1
0*2 = 0.  Add 0 to sum:     1
1*4 = 4.  Add 4 to sum:     5
1*8 = 8.  Add 8 to sum:     13
1*16 = 16.  Add 16 to sum:  29
1*32 = 32.  Add 32 to sum:  61
```

Binary to Decimal: Converting Between Bases







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  - Example: What is 111101 in decimal?

```
Sum starts with:            1
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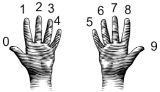
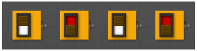
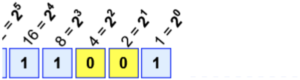
1*16 = 16.  Add 16 to sum:  29
1*32 = 32.  Add 32 to sum:  61
```

Binary to Decimal: Converting Between Bases





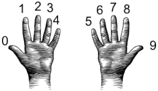


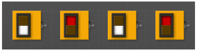
Example: 1×16 + 1×8 + 1×1 = 16+8+1 = 25

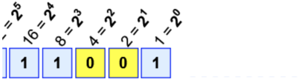
- Example: What is 10100100 in decimal?

  `Sum starts with:`

Binary to Decimal: Converting Between Bases





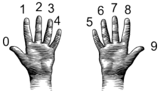


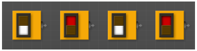
Example: 1×16 + 1×8 + 1×1 = 16+8+1 = 25

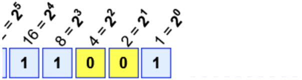
- Example: What is 10100100 in decimal?

```
Sum starts with:              0
0*2 = 0.  Add 0 to sum:
```

Binary to Decimal: Converting Between Bases







Example: 1×16 + 1×8 + 1×1 = 16+8+1 = 25

- Example: What is 10100100 in decimal?

```
Sum starts with:             0
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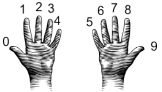
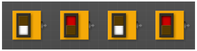
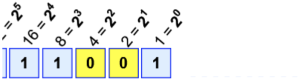
```

Binary to Decimal: Converting Between Bases





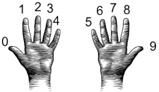


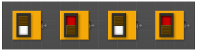
Example: 1×16 + 1×8 + 1×1 = 16+8+1 = 25

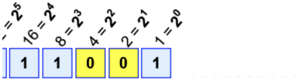
- Example: What is 10100100 in decimal?

```
Sum starts with:            0
0*2 = 0.  Add 0 to sum:     0
1*4 = 4.  Add 4 to sum:
```

Binary to Decimal: Converting Between Bases







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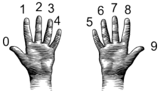
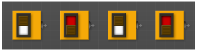
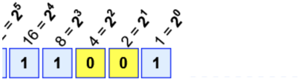
Binary to Decimal: Converting Between Bases







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```
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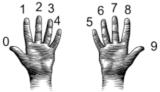
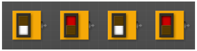
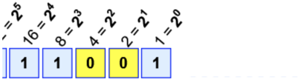
```

Binary to Decimal: Converting Between Bases







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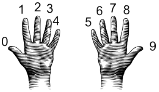
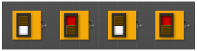
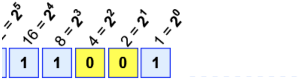
```

Binary to Decimal: Converting Between Bases







Example: 1×16 + 1×8 + 1×1 = 16+8+1 = 25

- Example: What is 10100100 in decimal?

```
Sum starts with:             0
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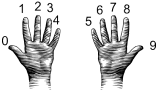
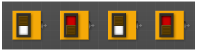
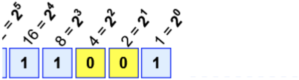
1*4 = 4.  Add 4 to sum:      4
0*8 = 0.  Add 0 to sum:      4
0*16 = 0.  Add 0 to sum:
```

Binary to Decimal: Converting Between Bases







Example: 1×16 + 1×8 + 1×1 = 16+8+1 = 25

- Example: What is 10100100 in decimal?

```
Sum starts with:             0
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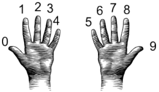
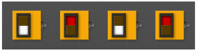
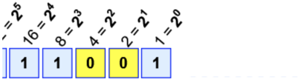
1*4 = 4.  Add 4 to sum:      4
0*8 = 0.  Add 0 to sum:      4
0*16 = 0.  Add 0 to sum:     4
```

Binary to Decimal: Converting Between Bases







Example: 1×16 + 1×8 + 1×1 = 16+8+1 = 25

- Example: What is 10100100 in decimal?

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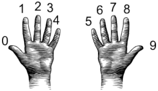

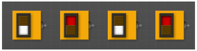

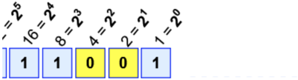

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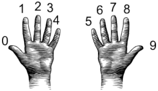

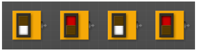

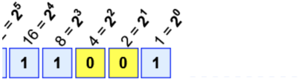

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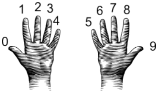

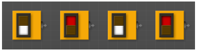

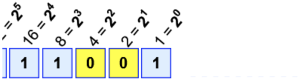

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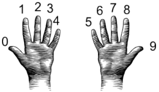

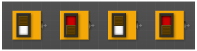

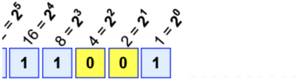

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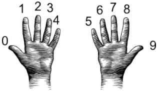
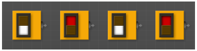
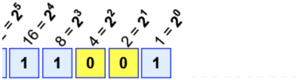
0*64 = 0.  Add 0 to sum:     36
1*128 = 0.  Add 128 to sum:
```

Binary to Decimal: Converting Between Bases







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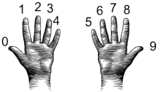
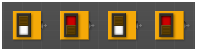
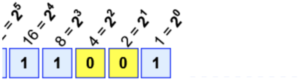
```

Binary to Decimal: Converting Between Bases







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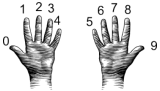
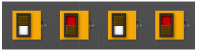
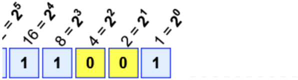
0*64 = 0.  Add 0 to sum:    36
1*128 = 0.  Add 128 to sum: 164
```

The answer is 164.

Design Challenge: Incrementers







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- Simplest arithmetic: add one (“increment”) a variable.

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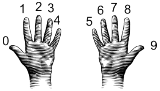

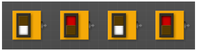

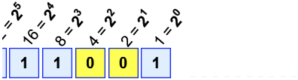

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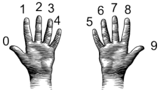

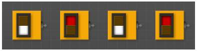

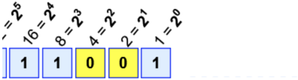

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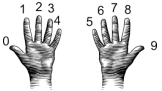

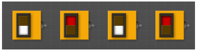

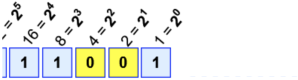

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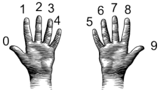

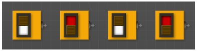

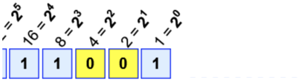

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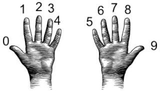

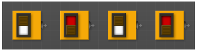

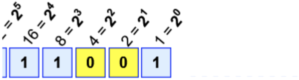

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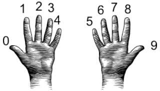

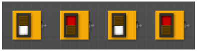

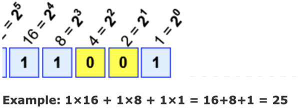

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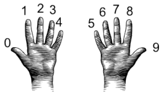

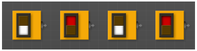

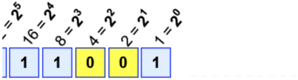

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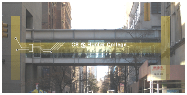
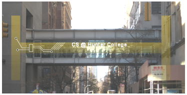
  Example: `"1001"` → `"1010"`

Recap



- Searching through data is a common task– built-in functions and standard design patterns for this.

Recap



- Searching through data is a common task– built-in functions and standard design patterns for this.
- Programming languages can be classified by the level of abstraction and direct access to data.

Today's Topics

- Design Patterns: Searching
- Python Recap
- Machine Language
- Machine Language: Jumps & Loops
- Binary & Hex Arithmetic
- **Final Exam: Format**

Final Overview: Administration

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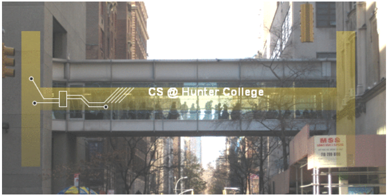
- Past exams available on webpage (includes answer keys).

Class Reminders!



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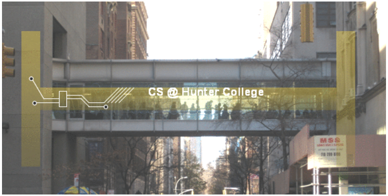

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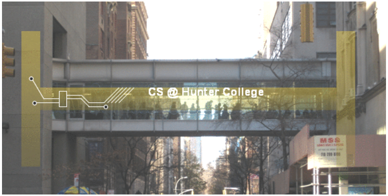

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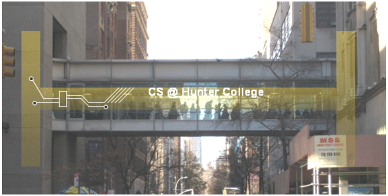
- Take the Lab Quiz on Gradescope by 9pm on Today
- Submit this class's programming assignments (programs 50-52)

Class Reminders!



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- At any point, visit our TA for help!!!