

CSci 127: Introduction to Computer Science



hunter.cuny.edu/csci

Frequently Asked Questions

From email and tutoring.

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- ▶ *Our TA Georgina 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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- **Design Patterns: Searching**
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Predict what the code will do:

```
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!')
else:
    print('Did not find 6 in the list.')|
```

Python Tutor

```
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(Demo with pythonTutor)

Design Pattern: Linear Search

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- Example of **linear search**.

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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.

Today's Topics



- Design Patterns: Searching
- **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
```

← These lines are comments

```
#Date: September 1, 2017
```

← (for us, not computer to read)

```
#This program prints: Hello, World!
```

← (this one also)

```
print("Hello, World!")
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← Prints the string "Hello, World!" to the screen

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- As well as definite loops & the turtle package:

The screenshot shows a Python code editor interface. On the left, the code file 'main.py' is open, containing the following Python script:

```
1 #A program that demonstrates turtles stamping
2
3 import turtle
4
5 taylor = turtle.Turtle()
6 taylor.color("purple")
7 taylor.shape("turtle")
8
9 for i in range(6):
10     taylor.forward(100)
11     taylor.stamp()
12     taylor.left(60)
```

On the right, the 'Result' tab displays the output of the script: a purple regular hexagon drawn on the screen, with each vertex marked by a purple star-like stamp.

Class 1: variables, data types, more on loops & range()

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 - e.g. [3, 1, 4, 5, 9] or ['violet', 'purple', 'indigo']

Class 1: variables, data types, more on loops & range()

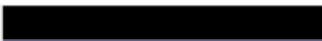
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 - ▶ **class variables**: for complex objects, like turtles.

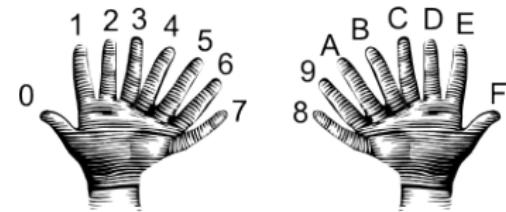
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 - ▶ **class variables**: for complex objects, like turtles.
- More on loops & ranges:

```
1 #Predict what will be printed:  
2  
3 for num in [2,4,6,8,10]:  
4     print(num)  
5  
6 sum = 0  
7 for x in range(0,12,2):  
8     print(x)  
9     sum = sum + x  
10  
11 print(sum)  
12  
13 for c in "ABCD":  
14     print(c)
```

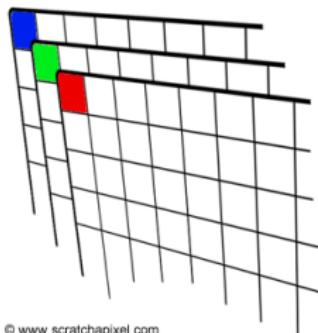
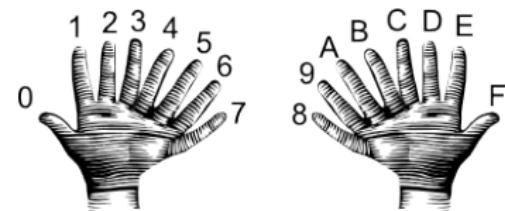
Class 2: colors, hex, slices, numpy & images

Color Name	HEX	Color
Black	#000000	
Navy	#000080	
DarkBlue	#00008B	
MediumBlue	#0000CD	
Blue	#0000FF	



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

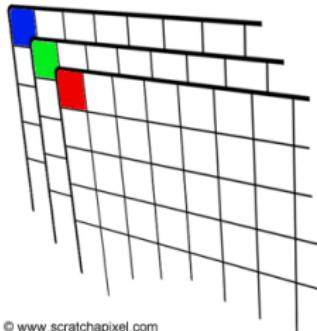
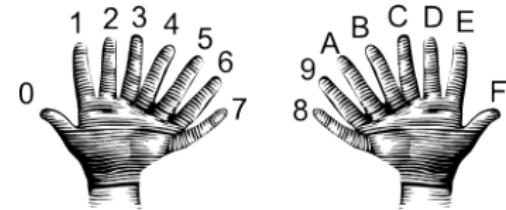
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© www.scratchapixel.com

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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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- First: specify inputs/outputs. *Input file name, output file name, upper, lower, left, right ("bounding box")*

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- First: specify inputs/outputs. *Input file name, output file name, upper, lower, left, right ("bounding box")*
- 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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- Next: translate to Python.

Class 3: design problem (cropping images) & decisions

```
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!")
```

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



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
1690,1,203,727,727,727,1,781
1771,21843,3623,2847,2847,2847,21843
1790,33131,4549,6159,1781,3827,49447
1800,60515,5740,6442,1755,4543,75955
1810,67540,6250,6840,2000,4543,109334
1820,123704,11487,8246,2792,6135,152056
1830,202589,20535,9049,3023,7082,242278
1840,311510,11013,14049,5346,10965,391114
1850,355441,12800,14891,5346,10965,415115
1860,813449,279122,32903,23593,25492,174777
1870,942292,419921,45468,37393,33029,1479103
1880,1164473,59943,5653,51980,33029,1911801
1890,1364473,66543,5653,51980,33029,2186134
1900,185093,116582,152999,200567,67621,2437202
1910,223342,1634351,2841,430980,8569,476683
1920,2233103,2018354,44601,44601,73201,11651,50048
1930,186713,2203936,1191325,1191325,1191325,4930446
1940,1889924,2498285,1297634,1394711,1394441,7454995
1950,1960101,2738175,1550949,1451277,191555,7891957
1960,1660101,2738175,1550949,1451277,191555,7891984
1970,1660101,2738175,1472701,1472701,135443,7891984
1980,1426285,2230936,1191325,1168972,352121,7071639
1990,1487536,2300664,1951598,1203789,378977,7322564
2000,1537195,2485326,2223379,1332450,419782,8080879
2010,1583873,2504705,2277722,1385108,447558,8175133
2015,1444518,2436733,2339150,1454446,474558,8056405

nycHistPop.csv

In Lab 6

Class 5: structured data, pandas, & more design

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

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Year,Borough,Brooklyn,Queens,Bronx,Staten Island,Total
1690,4937,2037,727,788,28423
1770,33131,4549,6159,1781,3827,49447
1800,60515,5740,6442,1755,4543,75955
1810,63545,5830,6532,1755,4574,75934
1820,123704,11187,8246,2792,4135,152056
1830,202589,20535,9049,3023,7082,242278
1840,312110,19113,14095,5348,10965,391114
1850,355441,218913,18895,5815,11584,411115
1860,813449,279122,32903,23593,25492,174777
1870,942292,419921,45468,37393,33029,1479103
1880,1164473,59943,5653,51980,33091,1911801
1890,1364473,70000,5653,51980,33091,1911801
1900,185093,116582,152999,200567,67621,2437202
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1920,2211103,2018354,44601,44601,73201,11651,50048
1930,1667137,1979128,172354,15834,4930446
1940,1889924,2498285,1297634,1394711,1374441,7454995
1950,1960101,2738175,1550949,1451277,191555,7991957
1960,1690331,2303219,1890941,1480711,191555,7981984
1970,1539231,2460711,1874473,1472701,135443,7984640
1980,1426285,2230936,1891325,1168972,352121,7071639
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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)
```

```
Source: https://en.wikipedia.org/wiki/Demographics_of_New_York_City.....  
All population figures are consistent with present-day boundaries.....  
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Year,Manhattan,Brooklyn,Queens,Bronx,Staten Island,Total  
1690,4937,2037,...,727,7881,10000  
1771,21843,36232,...,2847,28423  
1790,33131,4549,6159,1781,3827,49447  
1800,60515,5740,6442,1755,4543,75935  
1810,69121,6354,7040,1811,4937,85734  
1820,123704,11187,8246,2792,6135,152056  
1830,20589,20535,9049,3023,7082,242278  
1840,31150,10,113,1400,5346,10965,39114  
1850,35549,12800,18800,18800,18800,59115  
1860,613469,279122,32903,23593,25492,174777  
1870,942292,419921,45468,37393,33029,1479103  
1880,1164473,59940,5653,51980,33091,1911801  
1890,1365093,723112,68000,68000,68000,2181133  
1900,1850593,116582,152999,200567,67621,2437202  
1910,2331542,1634351,2841,430980,8569,476683  
1920,2231103,2018354,4460,4460,4460,73201,11651,593088  
1930,1867112,1867112,1867112,1867112,1867112,5930446  
1940,1889924,2690285,1297634,1394711,174441,7454995  
1950,1960101,2738175,1550849,1451277,191555,7991957  
1960,1690231,1690231,1690231,1690231,1690231,781984  
1970,1359331,1359331,1359331,1359331,1359331,781984  
1980,1426285,2230936,1891325,1168972,352121,7071639  
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nycHistPop.csv

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Year,Population  
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1771,21843,36231,...,2847,28423  
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1800,60515,5740,6442,1755,4543,75955  
1810,70000,6350,7000,1800,5300,93734  
1820,123704,11487,8246,2792,6135,152056  
1830,20589,20535,9049,3023,7082,142278  
1840,311510,110113,140000,5348,10965,391114  
1850,355491,128000,185000,58000,125000,45115  
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1880,1164473,59943,5653,51980,33001,1911801  
1890,1385000,710000,68000,58000,31800,2100000  
1900,1850093,116582,152999,200567,67621,2437202  
1910,2233142,1634351,2841,430980,8569,4766803  
1920,22421103,2018354,44600,720201,116500,500000  
1930,26711128,2079128,44600,720201,116500,500000  
1940,1889924,2690285,1297634,1394711,1374441,7454995  
1950,1960101,2738175,1550949,1451277,191555,7991957  
1960,1690000,2319319,1809000,1400000,1300000,781984  
1970,1539231,2465070,1874473,1472701,135443,768460  
1980,1426285,2230936,1891325,1168972,152121,7071639  
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nycHistPop.csv

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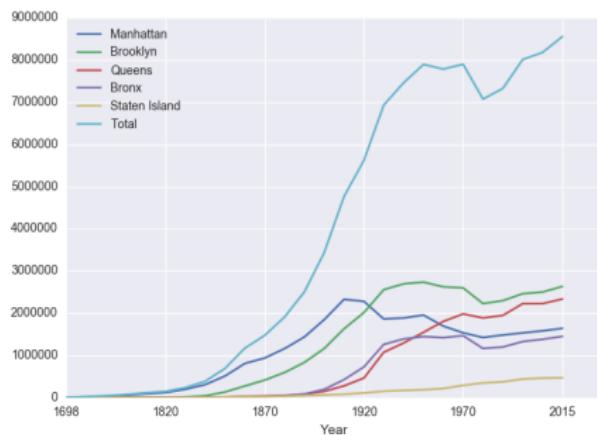
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import matplotlib.pyplot as plt  
import pandas as pd
```

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

```
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,Borough,Population  
1699,Manhattan, Brooklyn, Queens, Bronx, Staten Island, Total  
1771,21843,36231,2847,28423  
1790,33131,4549,6159,1781,3827,49447  
1800,60515,5740,6442,1755,4543,75935  
1810,71541,6350,7141,2000,5000,93734  
1820,123704,11187,8246,2792,6135,152056  
1830,202589,20535,9049,3023,7082,242278  
1840,312110,18013,14000,5348,10965,391114  
1850,455441,21800,18800,8500,15000,51154  
1860,613469,279122,32903,23593,25492,174777  
1870,942292,419921,45468,37393,33029,1479103  
1880,1164473,59943,5653,51980,33051,1911801  
1890,1400000,720000,680000,580000,450000,215134  
1900,1850993,1165852,152999,200567,67821,2437202  
1910,233142,1634351,2841,430980,85869,476683  
1920,2281103,2018354,44601,73201,11651,50048  
1930,2667123,2407128,35254,52545,5830,4930446  
1940,1949294,2469285,1297634,1394711,174441,7454995  
1950,1960101,2738175,1550849,1451277,191555,7991957  
1960,1690000,2100000,1800000,1500000,1200000,781984  
1970,1539231,2467071,2472071,1472701,135443,798462  
1980,1426285,2230936,1891325,1168972,352121,7071639  
1990,1497536,2300664,1951598,1320789,378977,7322564  
2000,1537195,2485326,2229379,1332450,413728,8080879  
2010,1583873,2504705,2216722,1385108,413728,8175133  
2015,1444518,2436733,2339150,1459446,474558,8059405
```

nycHistPop.csv

In Lab 6



Class 6: functions

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

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

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

if __name__ == "__main__":
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- 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: '))  
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print('Dinner total is', dTotal)
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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):
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- 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



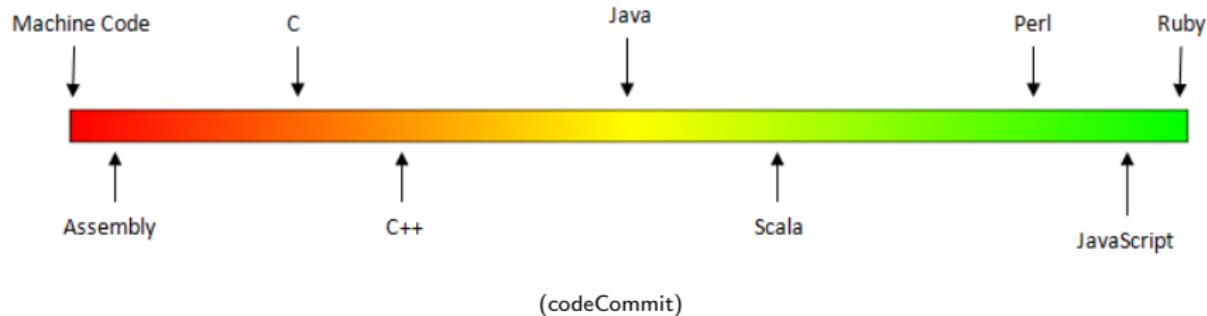
- Input/Output (I/O): `input()` and `print()`; pandas for CSV files
- Types:
 - ▶ Primitive: `int`, `float`, `bool`, `string`;
 - ▶ Container: lists (but not dictionaries/hashes or tuples)
- Objects: turtles (used but did not design our own)
- Loops: definite & indefinite
- Conditionals: if-elif-else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

Today's Topics



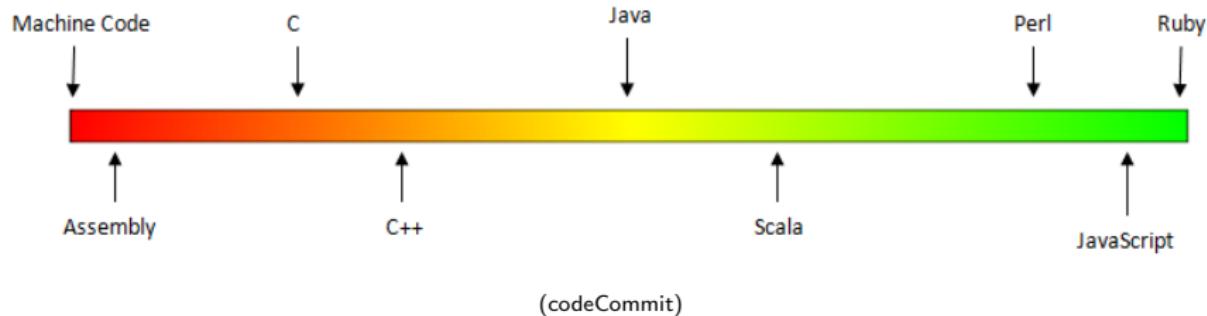
- Design Patterns: Searching
- Python Recap
- **Machine Language**
- Machine Language: Jumps & Loops
- Binary & Hex Arithmetic
- Final Exam: Format

Low-Level vs. High-Level Languages



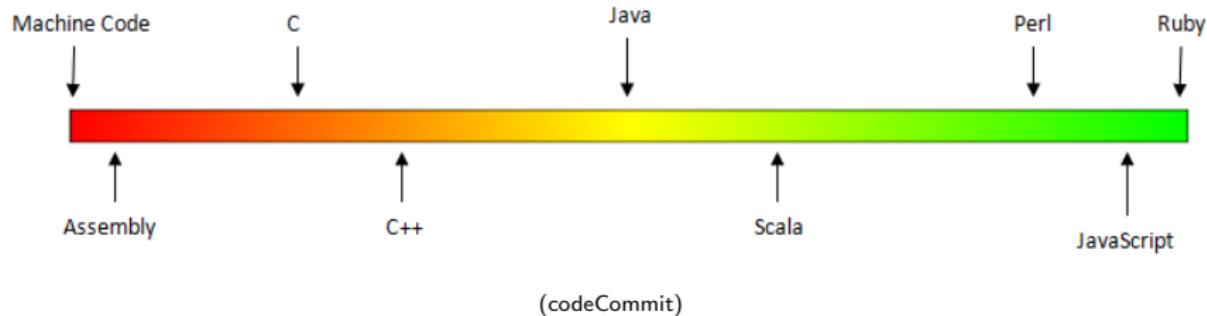
- Can view programming languages on a continuum.

Low-Level vs. High-Level Languages



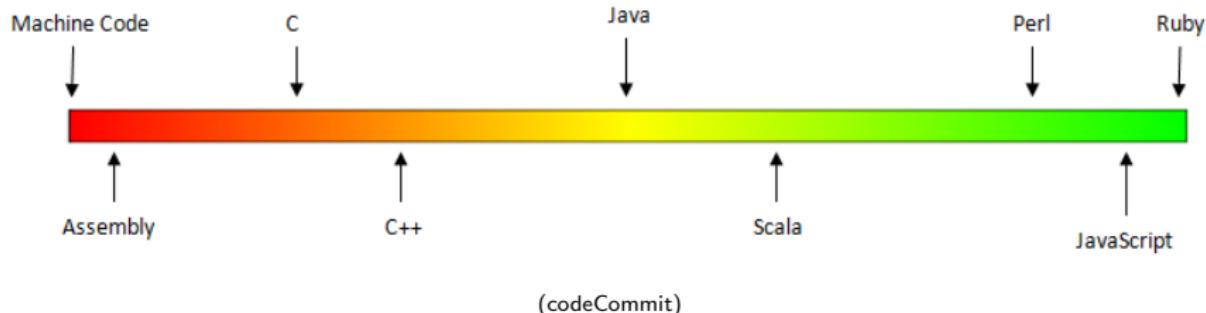
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Low-Level vs. High-Level Languages



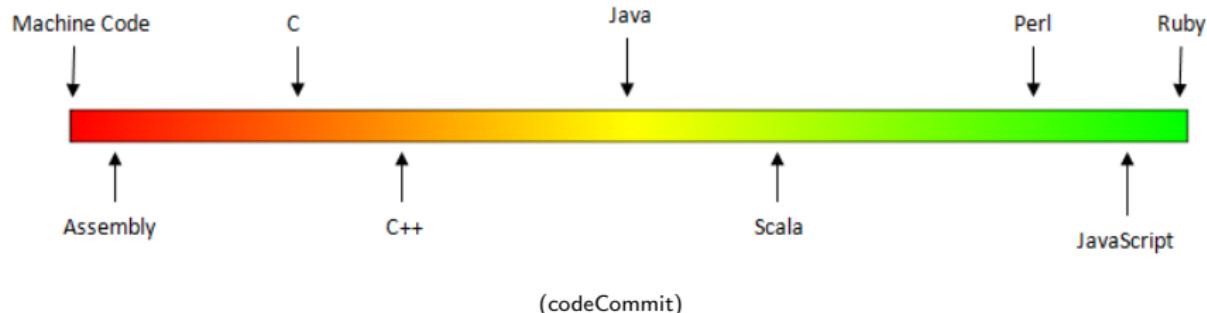
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- Those that have strong abstraction (allow programming paradigms independent of the machine details, such as complex variables, functions and looping that do not translate directly into machine code) are called **high-level languages**.
- Some languages,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

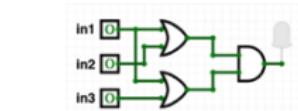
Processing

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.

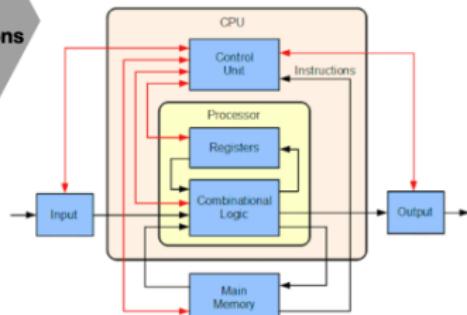
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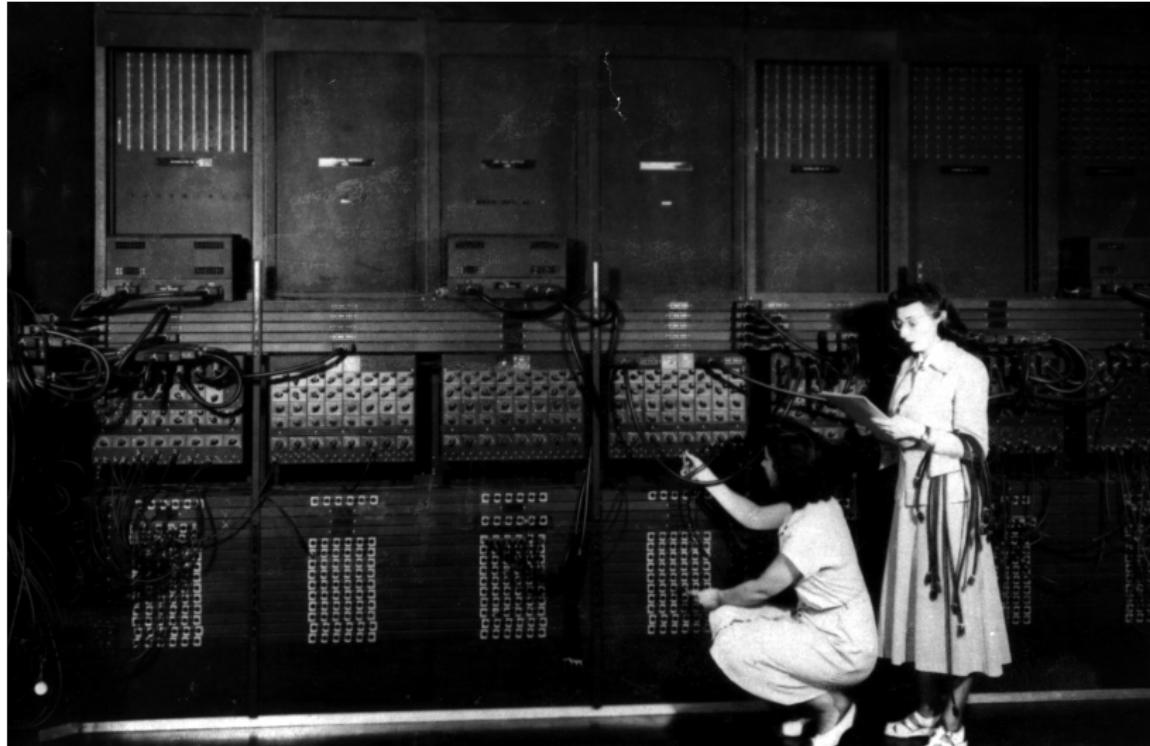
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```



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



Machine Language



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

Machine Language

```
I 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  NUMxDIZC .A .X .Y SP DP DB
; 00 E012 00110000 0000 0000 0002 CFFF 0000 00
g 2000

BREAK

PB PC  NUMxDIZC .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:UU .....
```

(wiki)

Machine Language

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

(wiki)

Machine Language

- We will be writing programs in a simplified machine language, WeMIPS.
 - It is based on a reduced instruction set computer (RISC) design, originally developed by the MIPS Computer Systems.

(wiki)

Machine Language

```

A 002300 C2 3B REP #3B
A 002302 7F CLC
A 002303 FB SED
A 002304 34 12 ADD #1224
A 002307 69 21 43 ADC #4321
A 002308 8F B3 77 B1 STA $0017B3
A 00230E D0 CLD
A 00230F E2 3B SEP #3B
A 002311 90 BPK
A 002312

F
PB PC Min:032C A X Y SP DP IR
; 00 2013 00110800 0550 0000 0002 CFFF 0000 00
$ 2000

BREAK

PB PC Min:032C A X Y SP DP IR
; 00 2013 00110800 0550 0000 0002 CFFF 0000 00
$ 77B3 77B3

$0017B3 55 55 00 00 00 00 00 00 00 00 00 00 00 00 00 00

```

(wiki)

- We will be writing programs in a simplified machine language, WeMIPS.
 - It is based on a reduced instruction set computer (RISC) design, originally developed by the MIPS Computer Systems.
 - Due to its small set of commands, processors can be designed to run those commands very efficiently.

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(wiki)

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 - It is based on a reduced instruction set computer (RISC) design, originally developed by the MIPS Computer Systems.
 - Due to its small set of commands, processors can be designed to run those commands very efficiently.
 - More in future architecture classes....

“Hello World!” in Simplified Machine Language

Line: 3 Go!

Show/Hide Demos

User Guide | Unit Tests | Docs

Addition Doubler Stav Looper Stack Test Hello World

Code Gen Save String Interactive Binary2 Decimal Decimal2 Binary

Debug

```
1 # Store 'Hello world!' at the top of the stack
2 ADDI $sp, $sp, -13
3 ADDI $t0, $zero, 72 # H
4 SB $t0, 0($sp)
5 ADDI $t0, $zero, 101 # e
6 SB $t0, 1($sp)
7 ADDI $t0, $zero, 108 # l
8 SB $t0, 2($sp)
9 ADDI $t0, $zero, 108 # i
10 SB $t0, 3($sp)
11 ADDI $t0, $zero, 111 # o
12 SB $t0, 4($sp)
13 ADDI $t0, $zero, 32 # (space)
14 SB $t0, 5($sp)
15 ADDI $t0, $zero, 119 # w
16 SB $t0, 6($sp)
17 ADDI $t0, $zero, 111 # o
18 SB $t0, 7($sp)
19 ADDI $t0, $zero, 114 # r
20 SB $t0, 8($sp)
21 ADDI $t0, $zero, 108 # l
22 SB $t0, 9($sp)
23 ADDI $t0, $zero, 100 # d
24 SB $t0, 10($sp)
25 ADDI $t0, $zero, 33 # !
26 SB $t0, 11($sp)
27 ADDI $t0, $zero, 0 # (null)
28 SB $t0, 12($sp)
29
30 ADDI $v0, $zero, 4 # 4 is for print string
31 ADDI $a0, $sp, 0
32 syscall           # print to the log
```

Step	Run	<input checked="" type="checkbox"/> Enable auto switching			
S	T	A	V	Stack	Log
s0:				10	
s1:				9	
s2:				9	
s3:				22	
s4:				696	
s5:				976	
s6:				927	
s7:				418	

(WeMIPS)

WeMIPS

The screenshot shows the WeMIPS debugger interface. At the top, there are tabs for 'Live', '3', 'Data', and 'ShowWhile Device'. Below these are navigation links: 'Addition Doubler', 'Stax', 'Looper', 'Stack Test', and 'Hello World'. There are also buttons for 'Code Gen Save String', 'Interactive', 'Binary2 Decimal', and 'Decimal2 Binary'. A 'Debug' button is also present.

The main area displays assembly code:

```
# Store 'Hello world!' at the top of the stack
1    ADDI $t0, $zero, 72 # N
2    ADDI $t1, $zero, 101 # e
3    ADDI $t2, $zero, 101 # m
4    ADDI $t3, $zero, 101 # l
5    ADDI $t4, $zero, 101 # o
6    ADDI $t5, $zero, 101 # w
7    ADDI $t6, $zero, 101 # r
8    ADDI $t7, $zero, 101 # i
9    ADDI $t8, $zero, 101 # n
10   ADDI $t9, $zero, 101 # d
11   ADDI $t10, $zero, 33 # !
12   ADDI $t11, $zero, 10 # '
13   ADDI $t12, $zero, 0 # null
14   ADDI $t13, $zero, 4 # 4 is for print string
15   ADDI $t14, $zero, 0 # point to the log
16   syscall
```

To the right of the assembly code is a memory dump table:

Step	Run	<input checked="" type="checkbox"/> Enable auto switching			
S	T	A	V	Stack	Log
s0				10	
s1				9	
s2				8	
s3				22	
s4				696	
s5				976	
s6				977	
s7				419	

(Demo with WeMIPS)

MIPS Commands

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 - **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

- **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

The screenshot shows the MARS MIPS simulator interface. The assembly code window displays the following instructions:

```
1 # Shows 'Hello, world!' at the top of the stack
2 .text
3 .globl _start
4 .type _start, @function
5 _start:
6    li $t0, 115902
7    li $t1, 115901
8    li $t2, 115900
9    li $t3, 115901
10   li $t4, 115900
11   li $t5, 115901
12   li $t6, 115900
13   addi $t0, $t0, $t0
14   addi $t1, $t1, $t1
15   addi $t2, $t2, $t2
16   addi $t3, $t3, $t3
17   addi $t4, $t4, $t4
18   addi $t5, $t5, $t5
19   addi $t6, $t6, $t6
20   addi $t0, $t0, 100
21   addi $t1, $t1, 100
22   addi $t2, $t2, 100
23   addi $t3, $t3, 100
24   addi $t4, $t4, 100
25   addi $t5, $t5, 100
26   addi $t6, $t6, 100
27   addi $t0, $t0, 4 # $t0 = 4 for print string
28   addi $t1, $t1, 0 # $t1 = 0 (null)
29   addi $t2, $t2, 0
30   addi $t3, $t3, 0
31   addi $t4, $t4, 0
32   addi $t5, $t5, 0
33   addi $t6, $t6, 0
34   # point to the log
```

The registers window shows the following values:

Reg	Value
\$0	10
\$1	9
\$2	8
\$3	22
\$4	0000
\$5	819
\$6	827
\$7	411

- **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

- **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

The screenshot shows a MIPS assembly editor interface. At the top, there's a menu bar with 'File', 'Edit', 'Get', 'Show/Hide Demo', 'Addition', 'Subtraction', 'Multiplication', 'Division', 'Hello World', 'Code Gen', 'Save String', 'Interactive', 'Decimal Decimal', 'Decimal Binary', and 'Debug'. Below the menu is a toolbar with 'Step', 'Run', 'Break', 'Create auto stepping', and a stack icon. On the right, there's a register table with columns for \$, T, A, V, Stack, and Log. The registers show values: \$0=10, \$1=9, \$2=8, \$3=22, \$4=000, \$5=819, \$6=827, and \$7=411. The assembly code area contains the following instructions:

```
1 # Shows 'Hello world' at the top of the stack
2 .text
3 .globl _start
4 .data
5 _start: .asciiz "Hello world\n"
6 .text
7 _start: li $t0, 111901
8 sb $t0, 111901
9 li $t1, 111902
10 sb $t1, 111902
11 li $t2, 111903
12 sb $t2, 111903
13 li $t3, 111904
14 sb $t3, 111904
15 li $t4, 111905
16 sb $t4, 111905
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24 sb $t8, 111909
25 li $t9, 111910
26 sb $t9, 111910
27 li $t10, 111911
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678 sb $t335, 111936
679 li $t336, 111937
680 sb $t336, 111937
681 li $t337, 111938
682 sb $t337, 111938
683 li $t338, 111939
684 sb $t338, 111939
685 li $t339, 111940
686 sb $t339, 111940
687 li $t340, 111941
688 sb $t340, 111941
689 li $t341, 111942
690 sb $t341, 111942
691 li $t342, 111943
692 sb $t342, 111943
693 li $t343, 111944
694 sb $t343
```

Challenge:

Line: 3 Go! Show/Hide Demos

User Guide | Unit Tests | Docs

Addition Doubler Stav Looper Stack Test Hello World

Code Gen Save String Interactive Binary2 Decimal Decimal2 Binary

Debug

```
1 # Store 'Hello world!' at the top of the stack
2 ADDI $sp, $sp, -13
3 ADDI $t0, $zero, 72 # H
4 SB $t0, 0($sp)
5 ADDI $t0, $zero, 101 # e
6 SB $t0, 1($sp)
7 ADDI $t0, $zero, 108 # l
8 SB $t0, 2($sp)
9 ADDI $t0, $zero, 108 # l
10 SB $t0, 3($sp)
11 ADDI $t0, $zero, 111 # o
12 SB $t0, 4($sp)
13 ADDI $t0, $zero, 32 # (space)
14 SB $t0, 5($sp)
15 ADDI $t0, $zero, 119 # w
16 SB $t0, 6($sp)
17 ADDI $t0, $zero, 111 # o
18 SB $t0, 7($sp)
19 ADDI $t0, $zero, 114 # r
20 SB $t0, 8($sp)
21 ADDI $t0, $zero, 108 # l
22 SB $t0, 9($sp)
23 ADDI $t0, $zero, 100 # d
24 SB $t0, 10($sp)
25 ADDI $t0, $zero, 33 # !
26 SB $t0, 11($sp)
27 ADDI $t0, $zero, 0 # (null)
28 SB $t0, 12($sp)
29
30 ADDI $v0, $zero, 4 # 4 is for print string
31 ADDI $a0, $sp, 0      # print to the log
32 syscall
```

Step Run Enable auto switching

S	T	A	V	Stack	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

(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.



A screenshot of a debugger interface. On the left is a window titled "Registers" showing CPU register values. On the right is a window titled "Assembly" showing assembly code. The assembly code includes instructions like LDI, ADD, and JUMP.

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.



Loops & Jumps in Machine Language

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Loops & Jumps in Machine Language

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- 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

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

Line: 18 Go!

Show/Hide Demos

User Guide | Unit Tests | Docs

```
1 ADDI $sp, $sp, -27      # Set up stack
2 ADDI $s3, $zero, 1       # Store 1 in a register
3 ADDI $t0, $zero, 97      # Set $t0 at 97 (a)
4 ADDI $s2, $zero, 26      # Use to test when you reach 26
5 SETUP: SB $t0, 0($sp)    # Next letter in $t0
6 ADDI $sp, $sp, 1         # Increment the stack
7 SUB $s2, $s2, $s3        # Decrease the counter by 1
8 ADDI $t0, $t0, 1         # Increment the letter
9 BEQ $s2, $zero, DONE     # Jump to done if $s2 == 0
10 J SETUP
11 J SETUP
12 DONE: ADDI $t0, $zero, 0 # Null (0) to terminate string
13 SB $t0, 0($sp)          # Add null to stack
14 ADDI $sp, $sp, -26      # Set up stack to print
15 ADDI $v0, $zero, 4       # 4 is for print string
16 ADDI $a0, $sp, 0         # Set $a0 to stack pointer
17 syscall                # Print to the log
```

(Demo
with
WeMIPS)

Step Run Enable auto switching

S T A V Stack Log

Clear Log

Emulation complete, returning to line 1

abcdefghijklmnopqrstuvwxyz

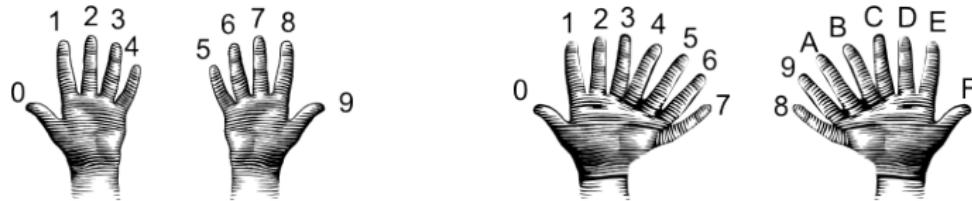


Today's Topics



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

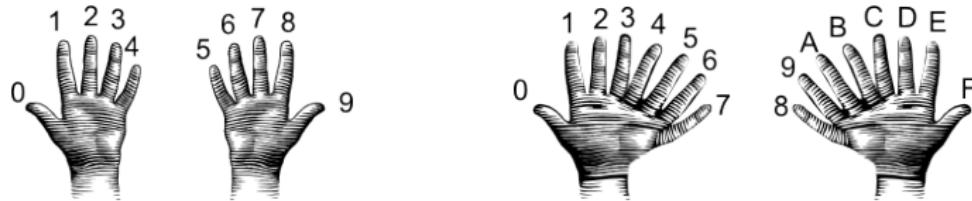
Hexadecimal to Decimal: Converting Between Bases



(from i-programmer.info)

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

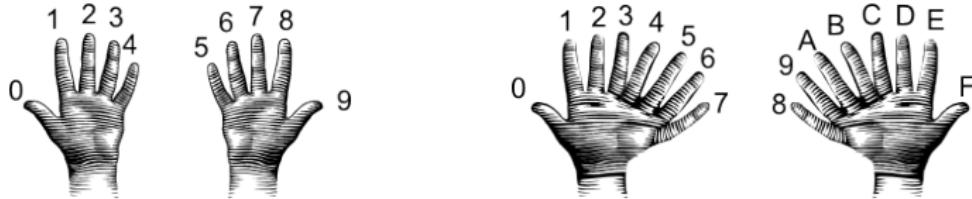
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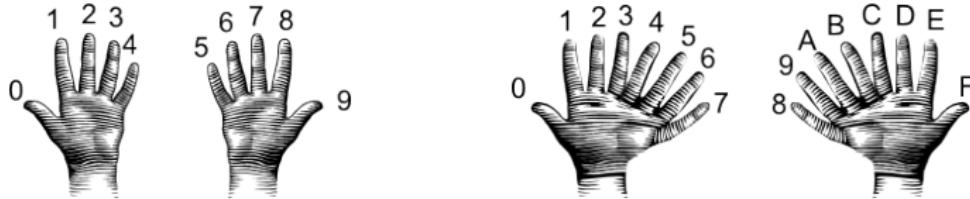
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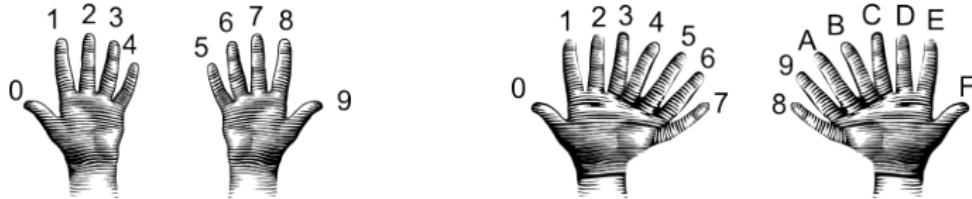
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2 in decimal is 2.

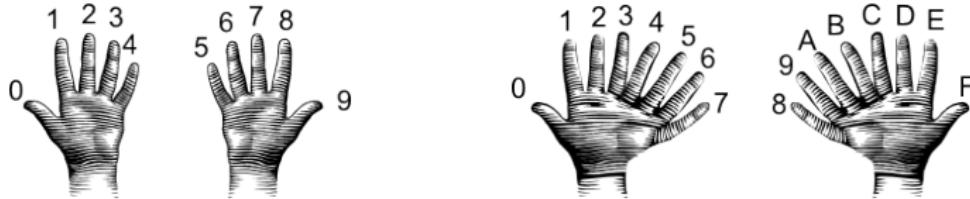
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 - Convert first digit to decimal and multiple by 16.
 - Convert second digit to decimal and add to total.
 - Example: what is 2A as a decimal number?
2 in decimal is 2. 2×16 is 32.

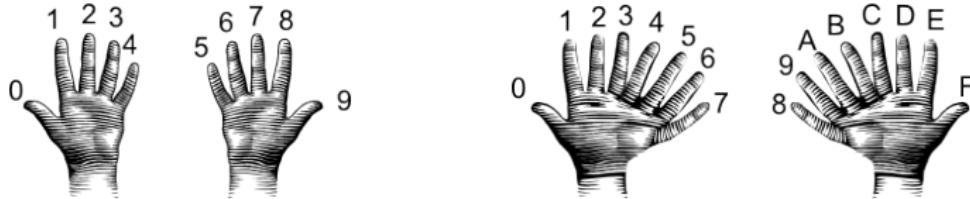
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 - Example: what is 2A as a decimal number?
2 in decimal is 2. 2×16 is 32.
A in decimal digits is 10.

Hexadecimal to Decimal: Converting Between Bases



(from i-programmer.info)

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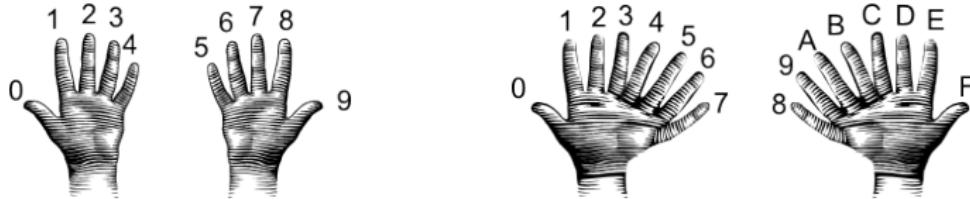
- Convert first digit to decimal and multiple by 16.
 - Convert second digit to decimal and add to total.
 - Example: what is 2A as a decimal number?

2 in decimal is 2. 2×16 is 32.

A in decimal digits is 10.

$32 + 10$ is 42.

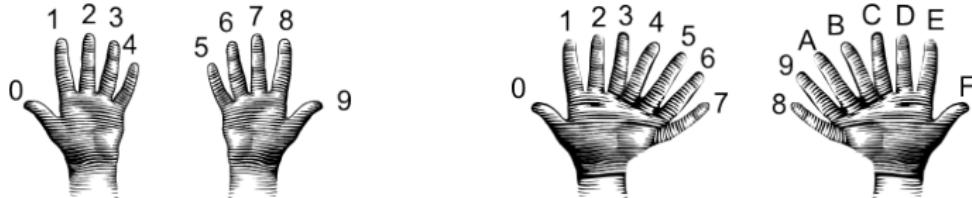
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A in decimal digits is 10.
 $32 + 10$ is 42.
Answer is 42.
 - Example: what is 99 as a decimal number?

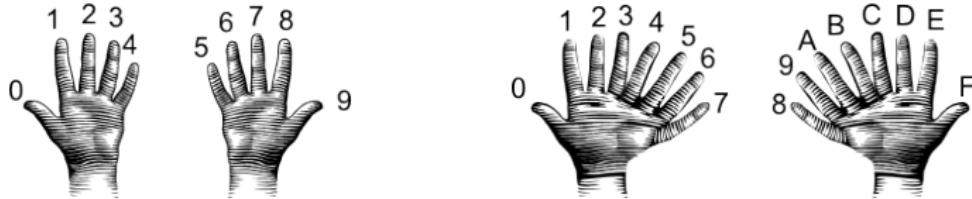
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 - Example: what is 2A as a decimal number?
2 in decimal is 2. 2×16 is 32.
A in decimal digits is 10.
 $32 + 10$ is 42.
Answer is 42.
 - Example: what is 99 as a decimal number?
9 in decimal is 9.

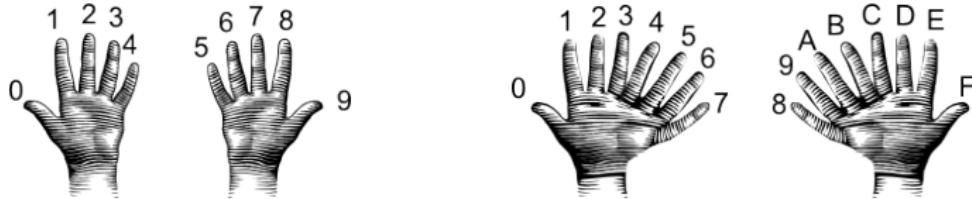
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 - Example: what is 2A as a decimal number?
2 in decimal is 2. 2×16 is 32.
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 $32 + 10$ is 42.
Answer is 42.
 - Example: what is 99 as a decimal number?
9 in decimal is 9. 9×16 is 144.

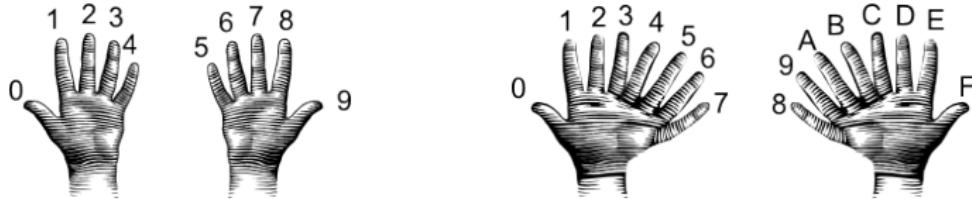
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 - Example: what is 2A as a decimal number?
2 in decimal is 2. 2×16 is 32.
A in decimal digits is 10.
 $32 + 10$ is 42.
Answer is 42.
 - Example: what is 99 as a decimal number?
9 in decimal is 9. 9×16 is 144.
9 in decimal digits is 9

Hexadecimal to Decimal: Converting Between Bases



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- 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?

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Answer is 42.

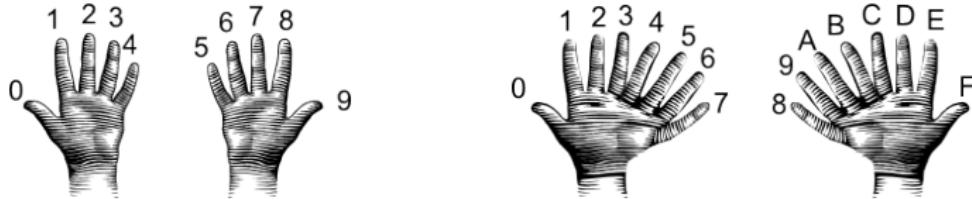
- Example: what is 99 as a decimal number?

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



(from i-programmer.info)

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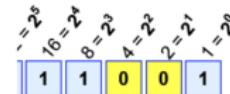
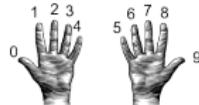
9 in decimal is 9. 9×16 is 144.

9 in decimal digits is 9

$144 + 9$ is 153.

Answer is 153.

Decimal to Binary: Converting Between Bases

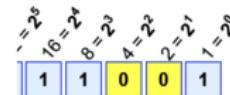
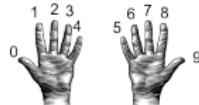


Example: $1 \times 16 + 1 \times 8 + 1 \times 1 = 16 + 8 + 1 = 25$

- From decimal to binary:

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

Decimal to Binary: Converting Between Bases

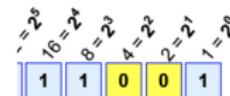
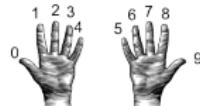


Example: $1 \times 16 + 1 \times 8 + 1 \times 1 = 16 + 8 + 1 = 25$

- From decimal to binary:

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- Divide remainder by $64 (= 2^6)$. Quotient is the next digit.

Decimal to Binary: Converting Between Bases

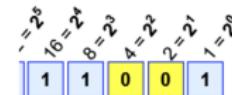


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Decimal to Binary: Converting Between Bases

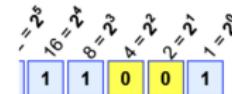
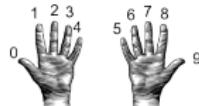


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Decimal to Binary: Converting Between Bases

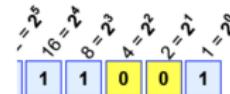


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Decimal to Binary: Converting Between Bases

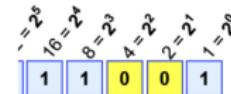
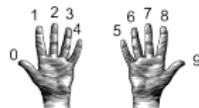


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- Divide remainder by $8 (= 2^3)$. Quotient is the next digit.
- Divide remainder by $4 (= 2^2)$. Quotient is the next digit.

Decimal to Binary: Converting Between Bases

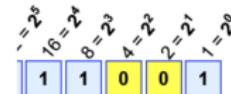
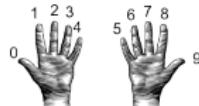


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- Divide remainder by $2 (= 2^1)$. Quotient is the next digit.

Decimal to Binary: Converting Between Bases

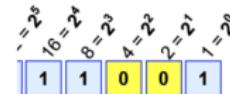
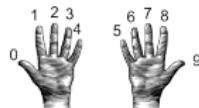


$$\text{Example: } 1 \times 16 + 1 \times 8 + 1 \times 1 = 16 + 8 + 1 = 25$$

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- Divide remainder by $2 (= 2^1)$. Quotient is the next digit.
- The last remainder is the last digit.

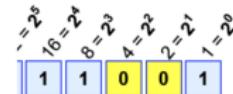
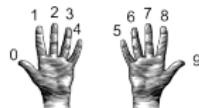
Decimal to Binary: Converting Between Bases



- 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.
- Divide remainder by 4 ($= 2^2$). Quotient is the next digit.
- Divide remainder by 2 ($= 2^1$). Quotient is the next digit.
- The last remainder is the last digit.
- Example: what is 130 in binary notation?

Decimal to Binary: Converting Between Bases



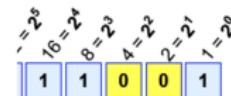
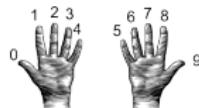
$$\text{Example: } 1 \times 16 + 1 \times 8 + 1 \times 1 = 16 + 8 + 1 = 25$$

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- Divide by $128 (= 2^7)$. Quotient is the first digit.
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- Divide remainder by $8 (= 2^3)$. Quotient is the next digit.
- Divide remainder by $4 (= 2^2)$. Quotient is the next digit.
- Divide remainder by $2 (= 2^1)$. Quotient is the next digit.
- The last remainder is the last digit.
- Example: what is 130 in binary notation?

$130/128 \text{ is } 1 \text{ rem } 2.$

Decimal to Binary: Converting Between Bases



Example: $1 \times 16 + 1 \times 8 + 1 \times 1 = 16 + 8 + 1 = 25$

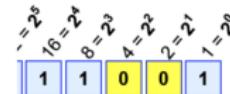
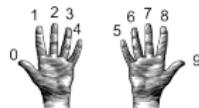
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- Example: what is 130 in binary notation?

130/128 is 1 rem 2. First digit is 1:

Decimal to Binary: Converting Between Bases



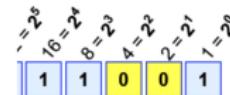
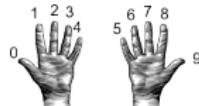
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130/128 is 1 rem 2. First digit is 1: 1...

2/64 is 0 rem 2.

Decimal to Binary: Converting Between Bases



Example: $1 \times 16 + 1 \times 8 + 1 \times 1 = 16 + 8 + 1 = 25$

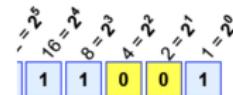
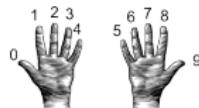
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$130/128$ is 1 rem 2. First digit is 1: 1...

$2/64$ is 0 rem 2. Next digit is 0:

Decimal to Binary: Converting Between Bases



$$\text{Example: } 1 \times 16 + 1 \times 8 + 1 \times 4 + 1 \times 2 + 1 \times 1 = 16 + 8 + 4 + 2 + 1 = 25$$

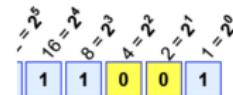
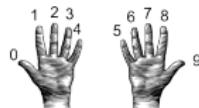
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130/128 is 1 rem 2. First digit is 1: 1...

2/64 is 0 rem 2. Next digit is 0: 10...

Decimal to Binary: Converting Between Bases



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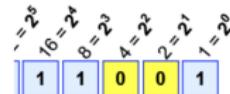
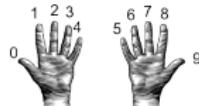
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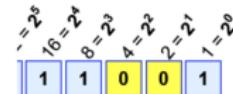
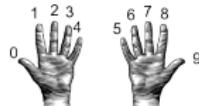
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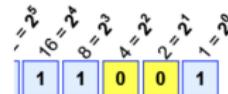
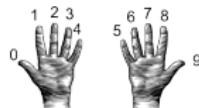
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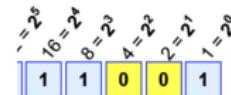
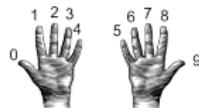
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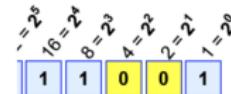
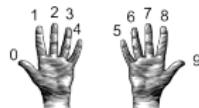
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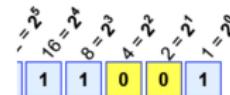
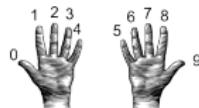
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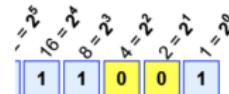
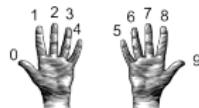
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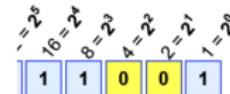
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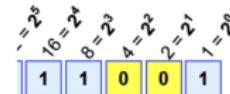
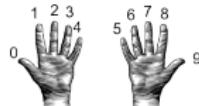
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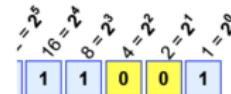
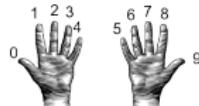
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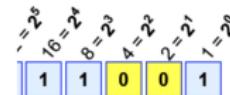
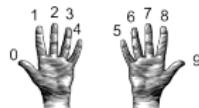
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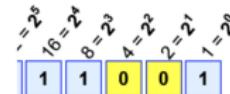
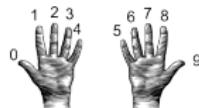
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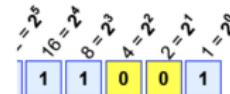
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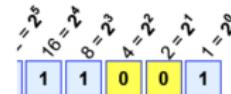
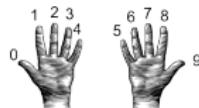
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- Divide remainder by $2 (= 2^1)$. Quotient is the next digit.
- The last remainder is the last digit.
- Example: what is 130 in binary notation?

130/128 is 1 rem 2. First digit is 1: 1...

2/64 is 0 rem 2. Next digit is 0: 10...

2/32 is 0 rem 2. Next digit is 0: 100...

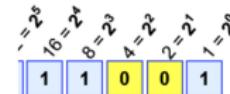
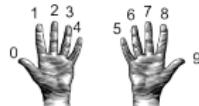
2/16 is 0 rem 2. Next digit is 0: 1000...

2/8 is 0 rem 2. Next digit is 0: 10000...

2/4 is 0 remainder 2. Next digit is 0: 100000...

2/2 is 1 rem 0. Next digit is 1: 1000001...

Decimal to Binary: Converting Between Bases



Example: $1 \times 16 + 1 \times 8 + 1 \times 1 = 16 + 8 + 1 = 25$

- 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.
- 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.
- Divide remainder by $4 (= 2^2)$. Quotient is the next digit.
- Divide remainder by $2 (= 2^1)$. Quotient is the next digit.
- The last remainder is the last digit.
- Example: what is 130 in binary notation?

130/128 is 1 rem 2. First digit is 1: 1...

2/64 is 0 rem 2. Next digit is 0: 10...

2/32 is 0 rem 2. Next digit is 0: 100...

2/16 is 0 rem 2. Next digit is 0: 1000...

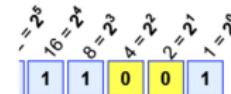
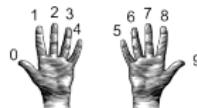
2/8 is 0 rem 2. Next digit is 0: 10000...

2/4 is 0 remainder 2. Next digit is 0: 100000...

2/2 is 1 rem 0. Next digit is 1: 1000001...

Adding the last remainder: 10000010

Decimal to Binary: Converting Between Bases



Example: $1 \times 16 + 1 \times 8 + 1 \times 1 = 16 + 8 + 1 = 25$

- 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.
- 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.
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- The last remainder is the last digit.
- Example: what is 130 in binary notation?

130/128 is 1 rem 2. First digit is 1: 1...

2/64 is 0 rem 2. Next digit is 0: 10...

2/32 is 0 rem 2. Next digit is 0: 100...

2/16 is 0 rem 2. Next digit is 0: 1000...

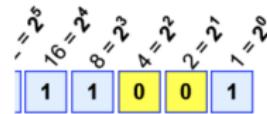
2/8 is 0 rem 2. Next digit is 0: 10000...

2/4 is 0 remainder 2. Next digit is 0: 100000...

2/2 is 1 rem 0. Next digit is 1: 1000001...

Adding the last remainder: 10000010

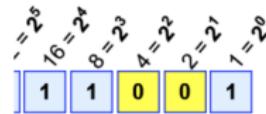
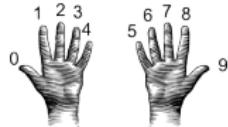
Decimal to Binary: Converting Between Bases



Example: $1 \times 16 + 1 \times 8 + 1 \times 1 = 16 + 8 + 1 = 25$

- Example: what is 99 in binary notation?

Decimal to Binary: Converting Between Bases

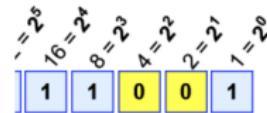


Example: $1 \times 16 + 1 \times 8 + 1 \times 1 = 16 + 8 + 1 = 25$

- Example: what is 99 in binary notation?

$99 / 128$ is 0 rem 99.

Decimal to Binary: Converting Between Bases

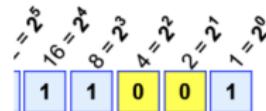


Example: $1 \times 16 + 1 \times 8 + 1 \times 4 + 1 \times 2 + 1 \times 1 = 16 + 8 + 4 + 2 + 1 = 25$

- Example: what is 99 in binary notation?

99/128 is 0 rem 99. First digit is 0:

Decimal to Binary: Converting Between Bases



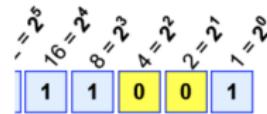
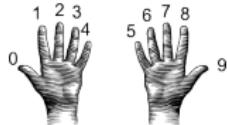
Example: $1 \times 16 + 1 \times 8 + 1 \times 1 = 16 + 8 + 1 = 25$

- Example: what is 99 in binary notation?

99/128 is 0 rem 99. First digit is 0: 0...

99/64 is 1 rem 35.

Decimal to Binary: Converting Between Bases



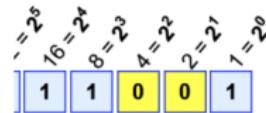
Example: $1 \times 16 + 1 \times 8 + 1 \times 4 + 0 \times 2 + 1 \times 1 = 16 + 8 + 4 + 1 = 25$

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99/64 is 1 rem 35. Next digit is 1:

Decimal to Binary: Converting Between Bases



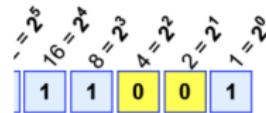
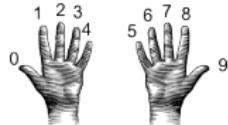
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Decimal to Binary: Converting Between Bases



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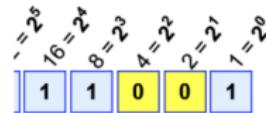
- Example: what is 99 in binary notation?

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.

Decimal to Binary: Converting Between Bases



Example: $1 \times 16 + 1 \times 8 + 1 \times 1 = 16 + 8 + 1 = 25$

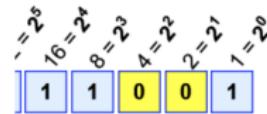
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Decimal to Binary: Converting Between Bases



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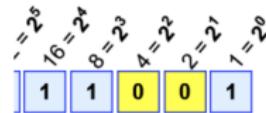
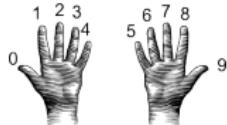
- Example: what is 99 in binary notation?

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...

Decimal to Binary: Converting Between Bases



Example: $1 \times 16 + 1 \times 8 + 1 \times 1 = 16 + 8 + 1 = 25$

- Example: what is 99 in binary notation?

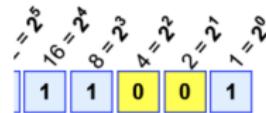
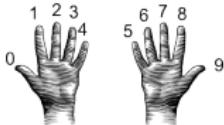
99/128 is 0 rem 99. First digit is 0: 0...

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3/16 is 0 rem 3.

Decimal to Binary: Converting Between Bases



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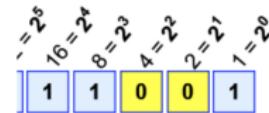
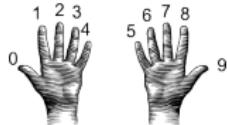
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Decimal to Binary: Converting Between Bases



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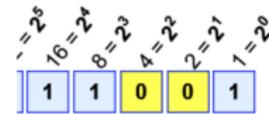
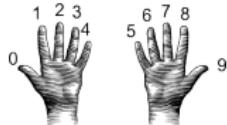
99/128 is 0 rem 99. First digit is 0: 0...

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...

Decimal to Binary: Converting Between Bases



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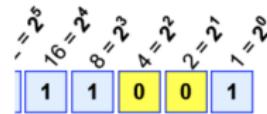
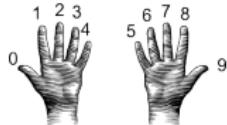
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3/8 is 0 rem 3.

Decimal to Binary: Converting Between Bases



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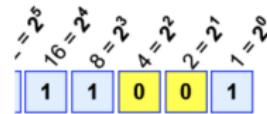
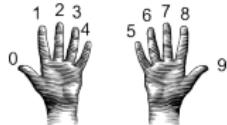
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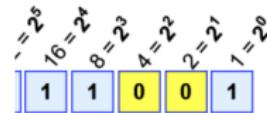
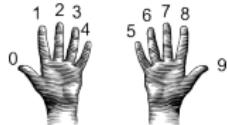
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Decimal to Binary: Converting Between Bases



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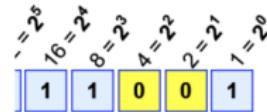
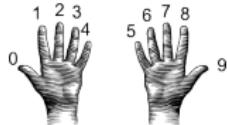
35/32 is 1 rem 3. Next digit is 1: 011...

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.

Decimal to Binary: Converting Between Bases



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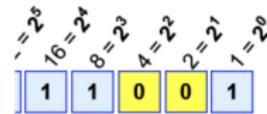
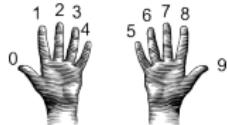
35/32 is 1 rem 3. Next digit is 1: 011...

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:

Decimal to Binary: Converting Between Bases



Example: $1 \times 16 + 1 \times 8 + 1 \times 1 = 16 + 8 + 1 = 25$

- 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...

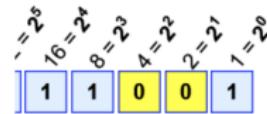
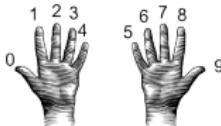
35/32 is 1 rem 3. Next digit is 1: 011...

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...

Decimal to Binary: Converting Between Bases



Example: $1 \times 16 + 1 \times 8 + 1 \times 4 + 0 \times 2 + 1 \times 1 = 16 + 8 + 4 + 1 = 25$

- Example: what is 99 in binary notation?

99/128 is 0 rem 99. First digit is 0: 0...

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35/32 is 1 rem 3. Next digit is 1: 011...

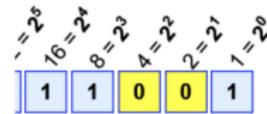
3/16 is 0 rem 3. Next digit is 0: 0110...

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.

Decimal to Binary: Converting Between Bases



Example: $1 \times 16 + 1 \times 8 + 1 \times 1 = 16 + 8 + 1 = 25$

- Example: what is 99 in binary notation?

99/128 is 0 rem 99. First digit is 0: 0...

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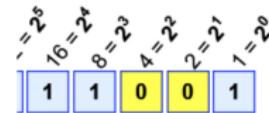
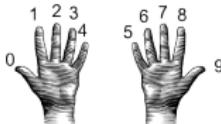
3/16 is 0 rem 3. Next digit is 0: 0110...

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:

Decimal to Binary: Converting Between Bases



Example: $1 \times 16 + 1 \times 8 + 1 \times 1 = 16 + 8 + 1 = 25$

- 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...

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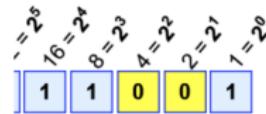
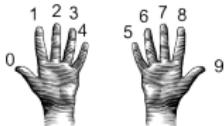
3/16 is 0 rem 3. Next digit is 0: 0110...

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: $1 \times 16 + 1 \times 8 + 1 \times 1 = 16 + 8 + 1 = 25$

- Example: what is 99 in binary notation?

99/128 is 0 rem 99. First digit is 0: 0...

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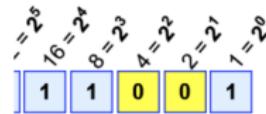
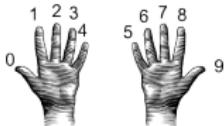
3/8 is 0 rem 3. Next digit is 0: 01100...

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: $1 \times 16 + 1 \times 8 + 1 \times 1 = 16 + 8 + 1 = 25$

- Example: what is 99 in binary notation?

99/128 is 0 rem 99. First digit is 0: 0...

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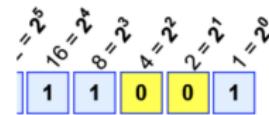
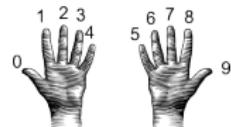
3/4 is 0 remainder 3. Next digit is 0: 011000...

3/2 is 1 rem 1. Next digit is 1: 0110001...

Adding the last remainder: 01100011

Answer is 1100011.

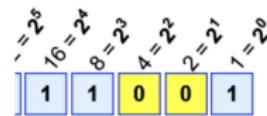
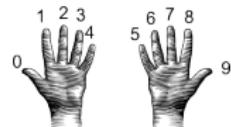
Binary to Decimal: Converting Between Bases



Example: $1 \times 16 + 1 \times 8 + 1 \times 1 = 16 + 8 + 1 = 25$

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

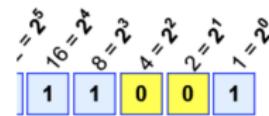
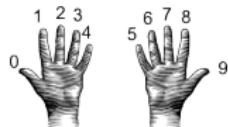
Binary to Decimal: Converting Between Bases



Example: $1 \times 16 + 1 \times 8 + 1 \times 1 = 16 + 8 + 1 = 25$

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

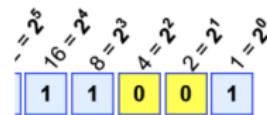
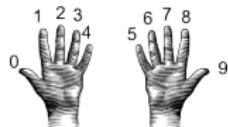
Binary to Decimal: Converting Between Bases



Example: $1 \times 16 + 1 \times 8 + 1 \times 1 = 16 + 8 + 1 = 25$

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

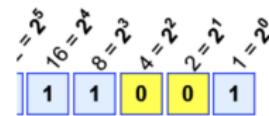
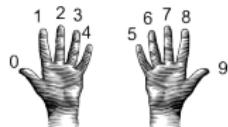
Binary to Decimal: Converting Between Bases



Example: $1 \times 16 + 1 \times 8 + 1 \times 1 = 16 + 8 + 1 = 25$

- 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

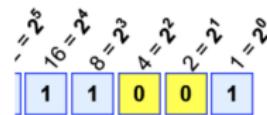
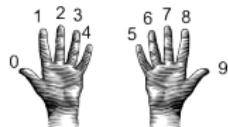


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Binary to Decimal: Converting Between Bases

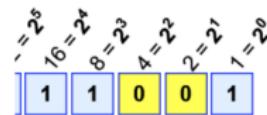
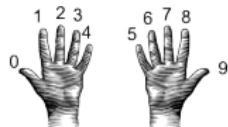


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- Multiply next digit by 2^4 . Add to sum.
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Binary to Decimal: Converting Between Bases

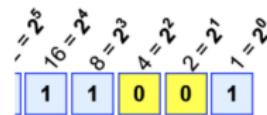
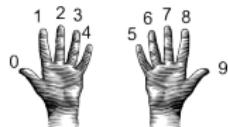


Example: $1 \times 16 + 1 \times 8 + 1 \times 4 + 0 \times 2 + 1 \times 1 = 16 + 8 + 4 + 0 + 1 = 25$

- From binary to decimal:

- Set sum = last digit.
- Multiply next digit by 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

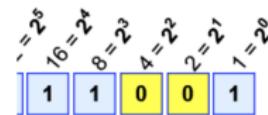
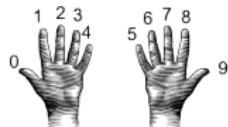


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- Multiply next digit by 2^2 . Add to sum.
- Multiply next digit by 2^3 . Add to sum.
- Multiply next digit by 2^4 . Add to sum.
- Multiply next digit by 2^5 . Add to sum.
- Multiply next digit by 2^6 . Add to sum.
- Multiply next digit by 2^7 . Add to sum.

Binary to Decimal: Converting Between Bases

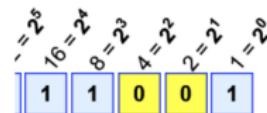


Example: $1 \times 16 + 1 \times 8 + 1 \times 4 + 0 \times 2 + 1 \times 1 = 16 + 8 + 4 + 0 + 1 = 25$

- From binary to decimal:

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- Multiply next digit by 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



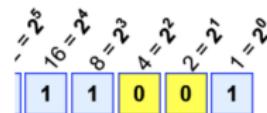
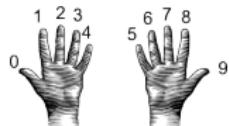
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- Multiply next digit by $4 = 2^2$. Add to sum.
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- Multiply next digit by $16 = 2^4$. Add to sum.
- Multiply next digit by $32 = 2^5$. Add to sum.
- Multiply next digit by $64 = 2^6$. Add to sum.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

Sum starts with:

Binary to Decimal: Converting Between Bases



Example: $1 \times 16 + 1 \times 8 + 1 \times 4 + 1 \times 1 = 16 + 8 + 4 + 1 = 25$

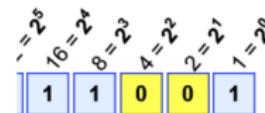
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- Multiply next digit by $8 = 2^3$. Add to sum.
- Multiply next digit by $16 = 2^4$. Add to sum.
- Multiply next digit by $32 = 2^5$. Add to sum.
- Multiply next digit by $64 = 2^6$. Add to sum.
- Multiply next digit by $128 = 2^7$. Add to sum.
- Sum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

Sum starts with: 1

$0 * 2 = 0$. Add 0 to sum:

Binary to Decimal: Converting Between Bases



Example: $1 \times 16 + 1 \times 8 + 1 \times 1 = 16 + 8 + 1 = 25$

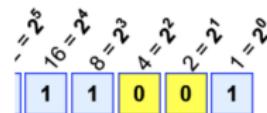
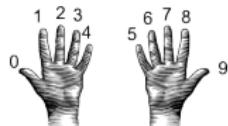
- From binary to decimal:

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

Binary to Decimal: Converting Between Bases



Example: $1 \times 16 + 1 \times 8 + 1 \times 1 = 16 + 8 + 1 = 25$

- From binary to decimal:

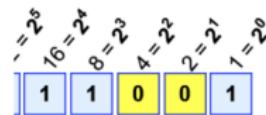
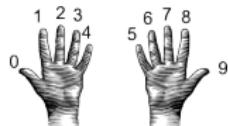
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- Multiply next digit by $8 = 2^3$. Add to sum.
- Multiply next digit by $16 = 2^4$. Add to sum.
- Multiply next digit by $32 = 2^5$. Add to sum.
- Multiply next digit by $64 = 2^6$. Add to sum.
- Multiply next digit by $128 = 2^7$. Add to sum.
- Sum 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: $1 \times 16 + 1 \times 8 + 1 \times 1 = 16 + 8 + 1 = 25$

- From binary to decimal:

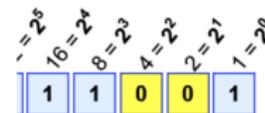
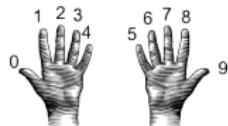
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- Multiply next digit by $64 = 2^6$. Add to sum.
- Multiply next digit by $128 = 2^7$. Add to sum.
- Sum is the decimal number.
- Example: What is 111101 in decimal?

Sum starts with: 1

$0 \times 2 = 0$. Add 0 to sum: 1

$1 \times 4 = 4$. Add 4 to sum: 5

Binary to Decimal: Converting Between Bases



Example: $1 \times 16 + 1 \times 8 + 1 \times 1 = 16 + 8 + 1 = 25$

- From binary to decimal:

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- Multiply next digit by $2 = 2^1$. Add to sum.
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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.
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- Sum is the decimal number.
- Example: What is 111101 in decimal?

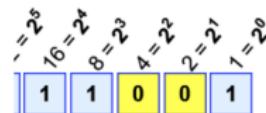
Sum starts with: 1

$0 \times 2 = 0$. Add 0 to sum: 1

$1 \times 4 = 4$. Add 4 to sum: 5

$1 \times 8 = 8$. Add 8 to sum:

Binary to Decimal: Converting Between Bases



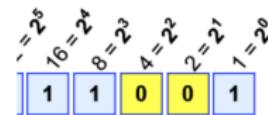
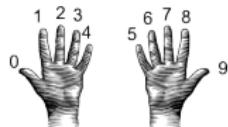
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- Multiply next digit by $64 = 2^6$. Add to sum.
- Multiply next digit by $128 = 2^7$. Add to sum.
- Sum is the decimal number.
- Example: What is 111101 in decimal?

Sum starts with: 1
 $0 \times 2 = 0$. Add 0 to sum: 1
 $1 \times 4 = 4$. Add 4 to sum: 5
 $1 \times 8 = 8$. Add 8 to sum: 13

Binary to Decimal: Converting Between Bases



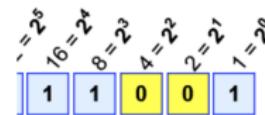
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- Multiply next digit by $32 = 2^5$. Add to sum.
- Multiply next digit by $64 = 2^6$. Add to sum.
- Multiply next digit by $128 = 2^7$. Add to sum.
- Sum is the decimal number.
- Example: What is 111101 in decimal?

Sum starts with: 1
 $0 \times 2 = 0$. Add 0 to sum: 1
 $1 \times 4 = 4$. Add 4 to sum: 5
 $1 \times 8 = 8$. Add 8 to sum: 13
 $1 \times 16 = 16$. Add 16 to sum:

Binary to Decimal: Converting Between Bases



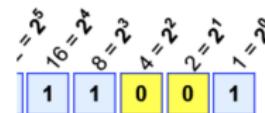
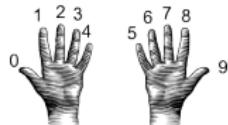
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- Multiply next digit by $128 = 2^7$. Add to sum.
- Sum is the decimal number.
- Example: What is 111101 in decimal?

Sum starts with: 1
 $0 \times 2 = 0$. Add 0 to sum: 1
 $1 \times 4 = 4$. Add 4 to sum: 5
 $1 \times 8 = 8$. Add 8 to sum: 13
 $1 \times 16 = 16$. Add 16 to sum: 29

Binary to Decimal: Converting Between Bases



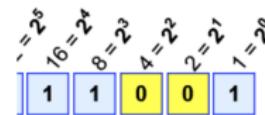
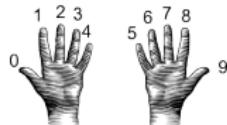
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- Multiply next digit by 2^7 . Add to sum.
- Sum is the decimal number.
- Example: What is 111101 in decimal?

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



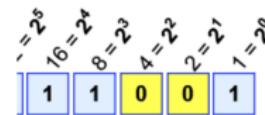
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- Multiply next digit by $32 = 2^5$. Add to sum.
- Multiply next digit by $64 = 2^6$. Add to sum.
- Multiply next digit by $128 = 2^7$. Add to sum.
- Sum is the decimal number.
- Example: What is 111101 in decimal?

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: 29
1*32 = 32. Add 32 to sum: 61

Binary to Decimal: Converting Between Bases



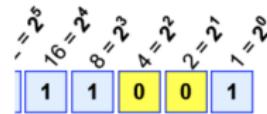
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- Example: What is 111101 in decimal?

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

Binary to Decimal: Converting Between Bases

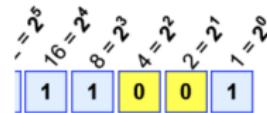
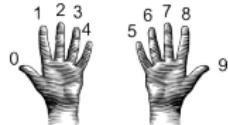


Example: $1 \times 16 + 1 \times 8 + 1 \times 1 = 16 + 8 + 1 = 25$

- Example: What is 10100100 in decimal?

Sum starts with:

Binary to Decimal: Converting Between Bases



Example: $1 \times 16 + 1 \times 8 + 1 \times 1 = 16 + 8 + 1 = 25$

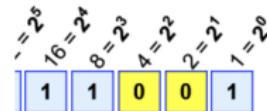
- Example: What is 10100100 in decimal?

Sum starts with:

0

$0 \times 2 = 0.$ Add 0 to sum:

Binary to Decimal: Converting Between Bases



Example: $1 \times 16 + 1 \times 8 + 1 \times 1 = 16 + 8 + 1 = 25$

- Example: What is 10100100 in decimal?

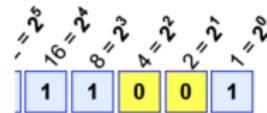
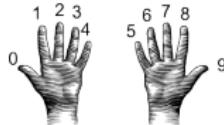
Sum starts with:

0

$0 \times 2 = 0.$ Add 0 to sum:

0

Binary to Decimal: Converting Between Bases



Example: $1 \times 16 + 1 \times 8 + 1 \times 1 = 16 + 8 + 1 = 25$

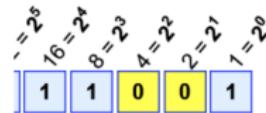
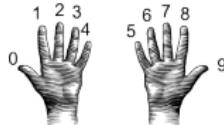
- Example: What is 10100100 in decimal?

Sum starts with: 0

$0 \times 2 = 0$. Add 0 to sum: 0

$1 \times 4 = 4$. Add 4 to sum:

Binary to Decimal: Converting Between Bases



Example: $1 \times 16 + 1 \times 8 + 1 \times 1 = 16 + 8 + 1 = 25$

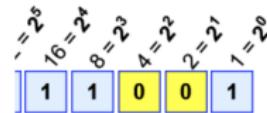
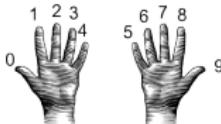
- Example: What is 10100100 in decimal?

Sum starts with: 0

$0 \times 2 = 0$. Add 0 to sum: 0

$1 \times 4 = 4$. Add 4 to sum: 4

Binary to Decimal: Converting Between Bases



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- Example: What is 10100100 in decimal?

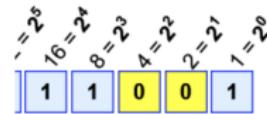
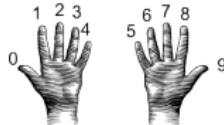
Sum starts with: 0

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Binary to Decimal: Converting Between Bases



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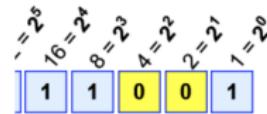
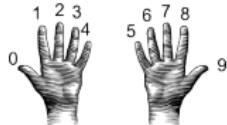
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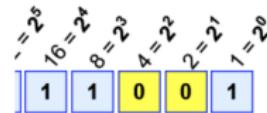
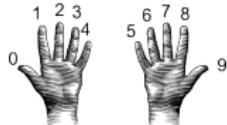
$0 \times 2 = 0$. Add 0 to sum: 0

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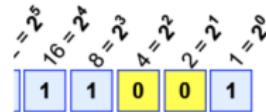
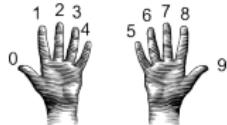
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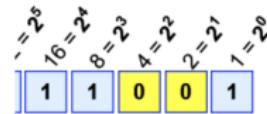
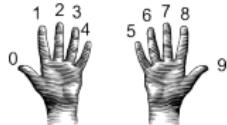
$1 \times 4 = 4$. Add 4 to sum: 4

$0 \times 8 = 0$. Add 0 to sum: 4

$0 \times 16 = 0$. Add 0 to sum: 4

$1 \times 32 = 32$. Add 32 to sum:

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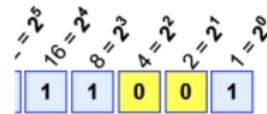
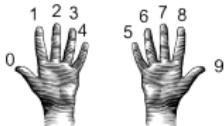
$1 \times 4 = 4$. Add 4 to sum: 4

$0 \times 8 = 0$. Add 0 to sum: 4

$0 \times 16 = 0$. Add 0 to sum: 4

$1 \times 32 = 32$. Add 32 to sum: 36

Binary to Decimal: Converting Between Bases



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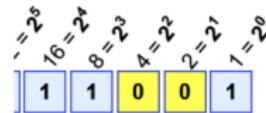
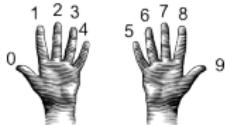
$0 \times 8 = 0$. Add 0 to sum: 4

$0 \times 16 = 0$. Add 0 to sum: 4

$1 \times 32 = 32$. Add 32 to sum: 36

$0 \times 64 = 0$. Add 0 to sum:

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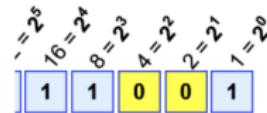
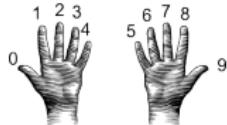
$0 \times 8 = 0$. Add 0 to sum: 4

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$1 \times 32 = 32$. Add 32 to sum: 36

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Binary to Decimal: Converting Between Bases



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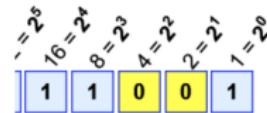
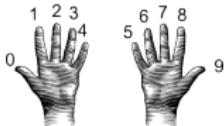
$0 \times 16 = 0$. Add 0 to sum: 4

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$0 \times 64 = 0$. Add 0 to sum: 36

$1 \times 128 = 0$. Add 128 to sum:

Binary to Decimal: Converting Between Bases

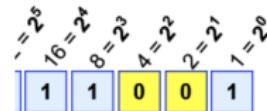
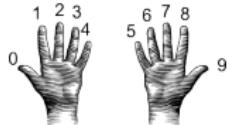


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$0 \times 64 = 0.$ Add 0 to sum:	36
$1 \times 128 = 0.$ Add 128 to sum:	164

Binary to Decimal: Converting Between Bases



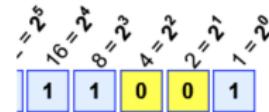
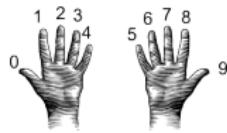
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$0 \times 64 = 0.$ Add 0 to sum:	36
$1 \times 128 = 0.$ Add 128 to sum:	164

The answer is 164.

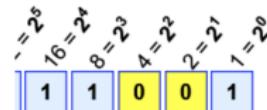
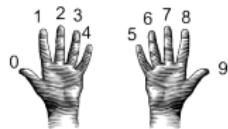
Design Challenge: Incrementers



Example: $1 \times 16 + 1 \times 8 + 1 \times 1 = 16 + 8 + 1 = 25$

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

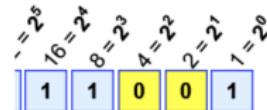
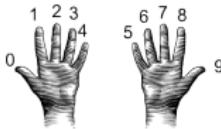
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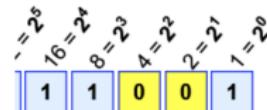
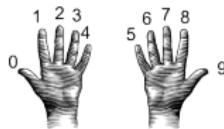


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Design Challenge: Incrementers



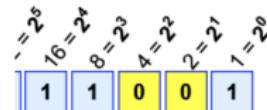
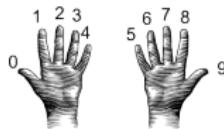
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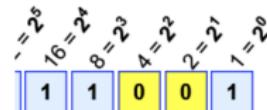
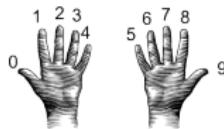
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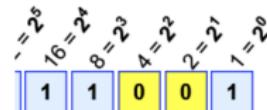
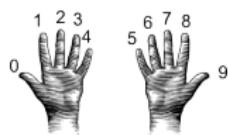
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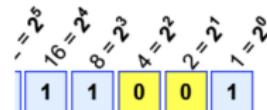
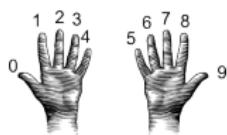
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Design Challenge: Incrementers



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Hint: Convert to numbers, increment, and convert back to strings.
- Challenge: Write an algorithm for incrementing binary numbers.
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**

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Class Reminders!



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