# Let's Learn Python (LLP)

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# Outline



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# About Me

# Yogesh Haribhau Kulkarni

Bio:

- 20+ years in CAD/Engineering software development
- Got Bachelors, Masters and Doctoral degrees in Mechanical Engineering (specialization: Geometric Modeling Algorithms).
- Currently doing Coaching in fields such as Data Science, Artificial Intelligence Machine-Deep Learning (ML/DL) and Natural Language Processing (NLP).
- Feel free to follow me at:
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# Overview

# Why Python?

- Readability.
- Ease of use.
- Fits in your head.
- Gets things done.
- Good libraries.
- Lookie what I did!.

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# Course Overview

- Python Fundamentals
- Object-Oriented Programming
- File Handling & I/O Operations
- Advanced Python Features
- Asynchronous Programming
- Real-world Projects

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# Introduction

- Python is a simple, yet powerful interpreted language.
- Numerous libraries: NumPy, SciPy, Matplotlib . . . .
- Named after Monty Python.
- Open Source and Free
- Invented by Guido van Rossum.

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# Python's Benevolent Dictator For Life

*"Python is an experiment in how much freedom programmers need. Too much freedom and nobody can read another's code; too little and expressiveness is endangered."*
- Guido van Rossum


(Reference: https://en.wikipedia.org/wiki/Guido_van_Rossum)

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# What is Python?

- Interpreted
- Object-oriented
- High-level
- Dynamic semantics
- Cross-platform
- Readability.

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# Compiled Languages

- Needs entire program
- Translates directly to machine codes
- Exe native and fast
- Usually statically typed
- Types known during compilation
- Change in type : recompilation
- Ideal for compute-heavy tasks
- E.g. C, C++, FORTRAN

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# Interpreted Languages

- Interpreted on the fly
- No need to compile: can execute right away
- Usually dynamically typed
- Non-syntax errors are detected only in run-time
- Slower than compiled languages
- Ideal for small tasks
- E.g. Python, Perl, PHP, Bash

Note: Python, at the beginning, loosely checks the program. Only at run time, line-by-line, it checks for errors. So, if the error statements are not in the running path, their error does not get reported. So, its a bit relaxed. Thats the objection for its use in production code, where strong type checking and error checking, upfront is essential.

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# JIT-Compiled Languages

- Between compiled and interpreted
- Code is initially interpreted, hotspots compiled
- Deduce types during compilation, can change in run-time
- Slower than compiled
- E.g. Java, C#

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# “C” guys to take pride in

- Python interpreter written in “C”
- Source code at www.python.org
- So, Python Interpreter is compiled exe

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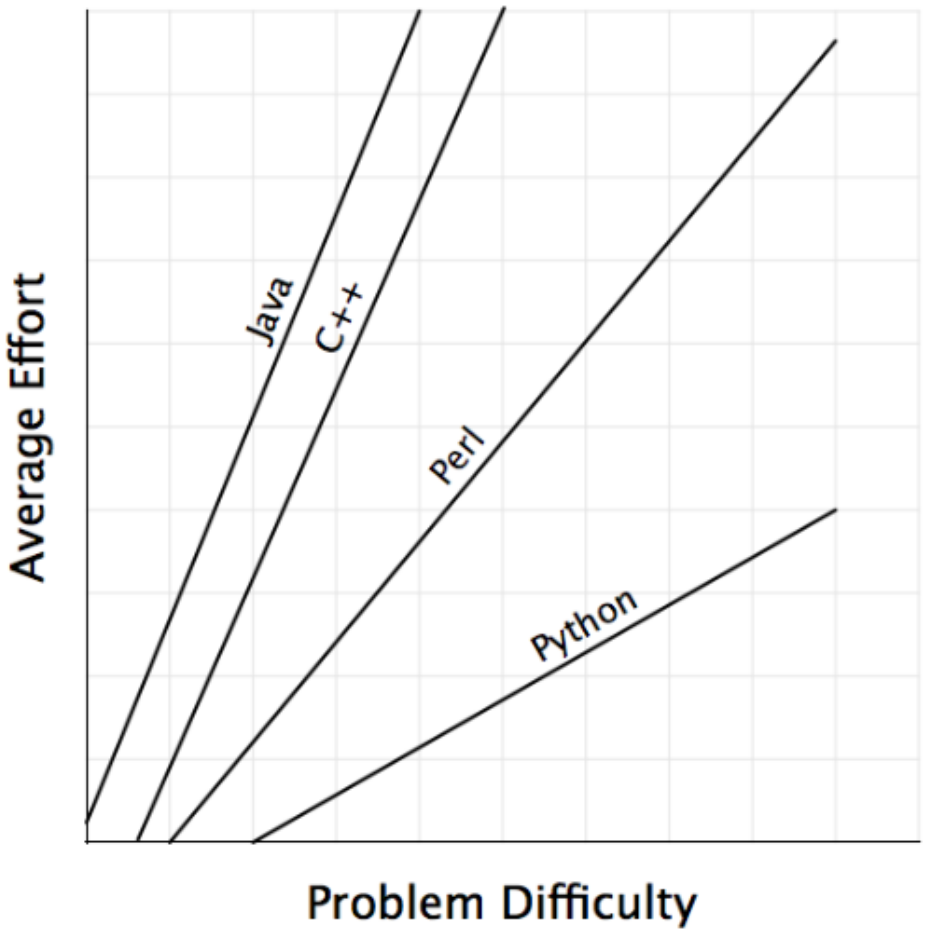
# Completely Controversial Observations about Languages

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# Important features

- Built-in high level data types: `strings`, `lists`, `dictionaries`, etc.
- Usual control structures: `if`, `if-else`, `if-elif-else`, `while`, `for`
- Levels of organization: `functions`, `classes`, `modules`, `packages`
- Extensions in C and C++ possible

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# Python 2 *vs* Python 3

- Two major versions 2.*, 3.*
- Python 2.7: Latest release in 2.x series
- Python 3.5: More polished syntax, removed inconsistencies

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# Variables & Data Types

- Dynamic typing - no declaration needed
- Basic types: int, float, str, bool
- Type conversion and checking
- Variable naming conventions
- Multiple assignment

```
# Variable assignment
name = "Alice"
age = 25
height = 5.6
is_student = True

# Type checking
print(type(age))  # <class 'int'>

# Type conversion
age_str = str(age)
price = float("19.99")

# Multiple assignment
x, y, z = 1, 2, 3

```

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# Data Structures - Lists, Tuples, Dicts, Sets

- Lists: ordered, mutable sequences
- Tuples: ordered, immutable sequences
- Dictionaries: key-value pairs
- Sets: unordered, unique elements
- Indexing and slicing

```python
# List
fruits = ["apple", "banana", "cherry"]
fruits.append("date")

# Tuple
coordinates = (10, 20)

# Dictionary
person = {"name": "Bob", "age": 30}
person["city"] = "NYC"

# Set
unique_nums = {1, 2, 3, 3, 2}
print(unique_nums)  # {1, 2, 3}

```

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# Control Flow - Conditional Statements

- if, elif, else statements
- Comparison operators ($==, !=, <, >, <=, >=$)
- Logical operators (and, or, not)
- Ternary operator
- Truthiness in Python

```
score = 85

if score >= 90:
    grade = "A"
elif score >= 80:
    grade = "B"
elif score >= 70:
    grade = "C"
else:
    grade = "F"

# Ternary operator
status = "Pass" if score >= 60 else "Fail"

# Logical operators
if score > 70 and score < 90:
    print("Good performance")

```

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# Control Flow - Loops

- for loops - iterate over sequences
- while loops - condition-based iteration
- break and continue statements
- range() function
- enumerate() for index tracking
- Loop with else clause

```python
# For loop with range
for i in range(5):
    print(i)

# Iterate over list
fruits = ["apple", "banana", "cherry"]
for fruit in fruits:
    print(fruit)

# While loop
count = 0
while count < 3:
    print(count)
    count += 1

# Enumerate
for idx, fruit in enumerate(fruits):
    print(f"{idx}: {fruit}")

```

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# Functions - Basics

- Function definition with def keyword
- Parameters and arguments
- Return values
- Default parameter values
- Docstrings for documentation
- Function as first-class objects

```python
# Basic function
def greet(name):
    """Greet a person by name"""
    return f"Hello, {name}!"

# Default parameters
def power(base, exp=2):
    return base ** exp

print(power(3))      # 9
print(power(3, 3))   # 27

# Multiple return values
def get_stats(numbers):
    return min(numbers), max(numbers)

min_val, max_val = get_stats([1, 5, 3])

```

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# Functions - Arguments & Scope

- Positional arguments
- Keyword arguments
- *args for variable arguments
- **kwargs for keyword arguments
- Local vs global scope
- LEGB rule (Local, Enclosing, Global, Built-in)

```python
# *args and **kwargs
def calculate(*args, **kwargs):
    total = sum(args)
    operation = kwargs.get('op', 'sum')
    return f"{operation}: {total}"

result = calculate(1, 2, 3, op="total")

# Scope example
x = 10  # Global

def modify():
    x = 5  # Local
    print(x)  # 5

modify()
print(x)  # 10 (global unchanged)
```

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# Lambda Functions & Built-in Functions

- Anonymous functions with lambda
- Single expression functions
- map() - apply function to iterable
- filter() - filter items by condition
- reduce() - aggregate values
- sorted() with key parameter

```python
# Lambda function
square = lambda x: x ** 2
print(square(5))  # 25

# map() – transform elements
numbers = [1, 2, 3, 4]
squared = list(map(lambda x: x**2, numbers))

# filter() – select elements
evens = list(filter(lambda x: x % 2 == 0, numbers))

# sorted with key
students = [("Alice", 85), ("Bob", 92)]
sorted_students = sorted(students,
                         key=lambda x: x[1],
                         reverse=True)

```

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# OOP - Classes & Objects

- Class definition with class keyword
- __init__ constructor method
- Instance variables (self)
- Instance methods
- Class vs instance attributes
- Encapsulation concept

```python
class Dog:
    # Class attribute
    species = "Canis familiaris"

    def __init__(self, name, age):
        # Instance attributes
        self.name = name
        self.age = age

    def bark(self):
        return f"{self.name} says Woof!"

    def description(self):
        return f"{self.name} is {self.age} years old"

# Create objects
buddy = Dog("Buddy", 3)
print(buddy.bark())
```

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# OOP - Inheritance

- Inheriting from parent classes
- super() to call parent methods
- Method overriding
- Multiple inheritance
- isinstance() and issubclass()
- Code reusability

```python
class Animal:
    def __init__(self, name):
        self.name = name

    def speak(self):
        pass

class Dog(Animal):
    def __init__(self, name, breed):
        super().__init__(name)
        self.breed = breed

    def speak(self):
        return f"{self.name} barks!"

class Cat(Animal):
    def speak(self):
        return f"{self.name} meows!"

dog = Dog("Max", "Labrador")
print(dog.speak())

```

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# OOP - Polymorphism & Special Methods

- Method overriding for polymorphism
- Duck typing in Python
- Special/magic methods (__str__, __repr__)
- Operator overloading (__add__, __eq__)
- __len__, __getitem__ for collections

```python
class Vector:
    def __init__(self, x, y):
        self.x = x
        self.y = y

    def __str__(self):
        return f"Vector({self.x}, {self.y})"

    def __add__(self, other):
        return Vector(self.x + other.x,
                      self.y + other.y)

    def __eq__(self, other):
        return self.x == other.x and \
               self.y == other.y

v1 = Vector(1, 2)
v2 = Vector(3, 4)
v3 = v1 + v2  # Calls __add__
print(v3)     # Calls __str__

```

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# OOP - Encapsulation & Properties

- Private attributes with __ prefix
- Protected attributes with _ prefix
- Property decorators (@property)
- Getters and setters
- Computed properties
- Data validation

```python
class BankAccount:
    def __init__(self, balance):
        self.__balance = balance  # Private

    @property
    def balance(self):
        return self.__balance

    @balance.setter
    def balance(self, amount):
        if amount < 0:
            raise ValueError("Balance cannot be
            negative")
        self.__balance = amount

    def deposit(self, amount):
        self.balance += amount

account = BankAccount(100)
account.deposit(50)
print(account.balance)  # 150
```

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# Project: Library Management System

```python
class Book:
    def __init__(self, title, author, isbn):
        self.title = title
        self.author = author
        self.isbn = isbn
        self.is_available = True

class Member:
    def __init__(self, name, member_id):
        self.name = name
        self.member_id = member_id
        self.borrowed_books = []

class Library:
    def __init__(self):
        self.books = []
        self.members = []

    def add_book(self, book): # TODO: Implement adding book to library
        pass

    def lend_book(self, member, book): # TODO: Check availability, update records
        pass

    def return_book(self, member, book): # TODO: Process book return
        pass
```

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# Project: Shopping Cart System

```python
class Product:
    def __init__(self, name, price, category):
        self.name = name
        self.price = price
        self.category = category

class ShoppingCart:
    def __init__(self):
        self.items = {}  # {product: quantity}

    def add_item(self, product, quantity=1): # TODO: Add product to cart
        pass

    def remove_item(self, product): # TODO: Remove product from cart
        pass

    def calculate_total(self, discount_code=None):
        # TODO: Calculate total with optional discount
        # Apply percentage discount if code valid
        pass

    def checkout(self): # TODO: Process payment and clear cart
        pass
```

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# File I/O - Reading & Writing Text Files

- open() function with modes (r, w, a)
- Reading: read(), readline(), readlines()
- Writing: write(), writelines()
- Context managers (with statement)
- File paths - absolute vs relative
- Automatic file closing

```python
# Reading a file
with open('data.txt', 'r') as file:
    content = file.read()
    print(content)

# Reading line by line
with open('data.txt', 'r') as file:
    for line in file:
        print(line.strip())

# Writing to a file
data = ["Line 1\n", "Line 2\n", "Line 3\n"]
with open('output.txt', 'w') as file:
    file.writelines(data)

# Appending to a file
with open('log.txt', 'a') as file:
    file.write("New log entry\n")

```

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# JSON Handling

- json module for JSON operations
- json.dump() - write to file
- json.dumps() - convert to string
- json.load() - read from file
- json.loads() - parse from string
- Handling nested structures

```python
import json

# Python dict to JSON
data = {
    "name": "Alice",
    "age": 30,
    "skills": ["Python", "SQL"]
}

# Write to file
with open('data.json', 'w') as f:
    json.dump(data, f, indent=4)

# Read from file
with open('data.json', 'r') as f:
    loaded_data = json.load(f)

# Convert to/from string
json_string = json.dumps(data)
parsed_data = json.loads(json_string)
```

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# CSV Processing

- csv module for CSV operations
- csv.reader() for reading
- csv.writer() for writing
- DictReader for dictionary access
- DictWriter for writing dicts
- Handling different delimiters

```python
import csv

# Reading CSV
with open('data.csv', 'r') as file:
    reader = csv.reader(file)
    for row in reader:
        print(row)

# Reading as dictionaries
with open('data.csv', 'r') as file:
    reader = csv.DictReader(file)
    for row in reader:
        print(row['name'], row['age'])

# Writing CSV
data = [['Name', 'Age'],
        ['Alice', 30],
        ['Bob', 25]]
with open('output.csv', 'w', newline='') as file:
    writer = csv.writer(file)
    writer.writerows(data)

```

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# Exception Handling

- try-except blocks
- Multiple except clauses
- else clause - executes if no exception
- finally clause - always executes
- Raising exceptions with raise
- Custom exception classes

```python
# Basic exception handling
try:
    result = 10 / 0
except ZeroDivisionError as e:
    print(f"Error: {e}")
except Exception as e:
    print(f"Unexpected error: {e}")
else:
    print("Success!")
finally:
    print("Cleanup code")

# Custom exception
class InvalidAgeError(Exception):
    pass

def set_age(age):
    if age < 0:
        raise InvalidAgeError("Age cannot be
            negative")
    return age

try:
    set_age(-5)
except InvalidAgeError as e:
    print(e)
```

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# Decorators Basics

- Functions as first-class objects
- Wrapper functions
- @ syntax for applying decorators
- functools.wraps for metadata
- Common use cases: logging, timing, caching
- Parameterized decorators

```python
import time
from functools import wraps

def timer(func):
    @wraps(func)
    def wrapper(*args, **kwargs):
        start = time.time()
        result = func(*args, **kwargs)
        end = time.time()
        print(f"{func.__name__} took
            {end-start:.2f}s")
        return result
    return wrapper

def log_call(func):
    @wraps(func)
    def wrapper(*args, **kwargs):
        print(f"Calling {func.__name__}")
        return func(*args, **kwargs)
    return wrapper

@timer
@log_call
def process_data(n):
    return sum(range(n))
```

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# Context Managers

- with statement for resource management
- __enter__ and __exit__ methods
- contextlib module
- @contextmanager decorator
- Automatic cleanup of resources
- Custom context managers

```python
from contextlib import contextmanager

# Custom context manager class
class FileManager:
    def __init__(self, filename, mode):
        self.filename = filename
        self.mode = mode

    def __enter__(self):
        self.file = open(self.filename, self.mode)
        return self.file

    def __exit__(self, exc_type, exc_val, exc_tb):
        self.file.close()

# Using decorator
@contextmanager
def timer_context():
    start = time.time()
    yield
    print(f"Elapsed: {time.time()-start:.2f}s")

with timer_context():
    # Code to time
    time.sleep(1)
```

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# Project: CSV Data Processor

```python
import csv
import logging

def log_operation(func):
    """Decorator to log operations"""
    def wrapper(*args, **kwargs):
        logging.info(f"Starting {func.__name__}")
        try:
            result = func(*args, **kwargs)
            logging.info(f"Completed {func.__name__}")
            return result
        except Exception as e:
            logging.error(f"Error in {func.__name__}: {e}")
            raise
    return wrapper

class CSVProcessor:
    def __init__(self, input_file):
        self.input_file = input_file
    @log_operation
    def read_data(self): # TODO: Read CSV with error handling
        pass
    @log_operation
    def filter_data(self, condition): # TODO: Filter rows based on condition
        pass
    @log_operation
    def transform_data(self, transformation): # TODO: Apply transformation to columns
        pass
    @log_operation
    def export_results(self, output_file): # TODO: Write processed data to new CSV
        pass
```

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# Project: Config File Manager

```python
import json
import yaml
from contextlib import contextmanager
from datetime import datetime

class ConfigManager:
    def __init__(self, config_file):
        self.config_file = config_file
        self.config = {}

    @contextmanager
    def config_context(self): # TODO: Backup current config
        """Context manager for safe config operations"""
        try:
            yield self
        except Exception as e: # TODO: Restore from backup
            raise
        finally: # TODO: Cleanup
            pass

    def load_config(self): # TODO: Load JSON/YAML config
        pass
    def validate_config(self, schema): # TODO: Validate against schema
        pass
    def save_config(self): # TODO: Save config with backup
        pass
    def get(self, key, default=None): # TODO: Get config value with dot notation
        pass
```

# Comprehensions

- List comprehensions for concise lists
- Dict comprehensions for dictionaries
- Set comprehensions for unique values
- Conditional logic in comprehensions
- Nested comprehensions
- Performance benefits

```python
# List comprehension
squares = [x**2 for x in range(10)]
evens = [x for x in range(20) if x % 2 == 0]

# Dict comprehension
word_lengths = {word: len(word)
                for word in ['apple', 'banana']}

# Set comprehension
unique_squares = {x**2 for x in range(-5, 6)}

# Nested comprehension
matrix = [[i*j for j in range(3)]
          for i in range(3)]

# Conditional expression
results = [x if x > 0 else 0
           for x in range(-5, 5)]
```

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# Generators & Generator Expressions

- Memory-efficient iteration
- yield keyword for generators
- Generator expressions (lazy evaluation)
- next() function
- StopIteration exception
- Infinite sequences

```python
# Generator function
def fibonacci(n):
    a, b = 0, 1
    for _ in range(n):
        yield a
        a, b = b, a + b

# Using generator
for num in fibonacci(10):
    print(num)

# Generator expression
squares_gen = (x**2 for x in range(1000000))
print(next(squares_gen))  # 0
print(next(squares_gen))  # 1

# Infinite generator
def infinite_counter():
    n = 0
    while True:
        yield n
        n += 1
```

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# Iterators & Advanced Iteration

- Iterator protocol: __iter__ and __next__
- itertools module
- Chain, cycle, repeat functions
- Combinations and permutations
- zip() and zip_longest()
- Creating custom iterators

```python
from itertools import islice, chain, cycle

# Custom iterator
class CountDown:
    def __init__(self, start):
        self.current = start

    def __iter__(self):
        return self

    def __next__(self):
        if self.current <= 0:
            raise StopIteration
        self.current -= 1
        return self.current + 1

# Using itertools
combined = chain([1, 2], [3, 4])
first_five = islice(range(100), 5)

# Zip multiple iterables
names = ['Alice', 'Bob']
ages = [30, 25]
for name, age in zip(names, ages):
    print(f"{name}: {age}")

```

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# Concurrent Operations - Threading

- threading module for concurrency
- Thread creation and management
- Global Interpreter Lock (GIL)
- Thread-safe operations
- concurrent.futures.ThreadPoolExecutor
- Use for I/O-bound tasks

```python
import threading
from concurrent.futures import ThreadPoolExecutor
import time

# Basic threading
def task(name):
    print(f"Task {name} starting")
    time.sleep(1)
    print(f"Task {name} complete")

threads = []
for i in range(3):
    t = threading.Thread(target=task, args=(i,))
    threads.append(t)
    t.start()

for t in threads:
    t.join()

# ThreadPoolExecutor
with ThreadPoolExecutor(max_workers=3) as executor:
    futures = [executor.submit(task, i) for i in range(3)]

```

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# Async/Await Basics

- Asynchronous programming concepts
- async def for coroutines
- await keyword for awaiting
- Event loop with asyncio
- Concurrent execution of coroutines
- Non-blocking I/O operations

```python
import asyncio

# Basic async function
async def fetch_data(id):
    print(f"Fetching {id}...")
    await asyncio.sleep(1)  # Simulates I/O
    print(f"Fetched {id}")
    return f"Data {id}"

# Running coroutines
async def main():
    # Sequential
    result1 = await fetch_data(1)

    # Concurrent
    results = await asyncio.gather(
        fetch_data(2),
        fetch_data(3),
        fetch_data(4)
    )
    print(results)

# Run event loop
asyncio.run(main())
```

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# Project: Async Web Scraper

```python
import asyncio
import aiohttp
from bs4 import BeautifulSoup

class AsyncWebScraper:
    def __init__(self, urls):
        self.urls = urls
        self.results = []

    async def fetch_url(self, session, url):
        """Fetch single URL asynchronously"""
        try: # TODO: Get HTML content, Parse with BeautifulSoup, Extract required data
            async with session.get(url) as response:
                pass
        except Exception as e:
            print(f"Error fetching {url}: {e}")
            return None

    async def scrape_all(self): # TODO: Gather all results concurrently
        async with aiohttp.ClientSession() as session:
            tasks = [self.fetch_url(session, url) for url in self.urls]
            pass

    async def save_results(self, filename): # TODO: Write results to file
        pass

# asyncio.run(scraper.scrape_all())
```

# Project: Concurrent File Processor

```python
import asyncio
import aiofiles
from pathlib import Path

class ConcurrentFileProcessor:
    def __init__(self, file_paths):
        self.file_paths = file_paths
        self.progress = {}

    async def process_file(self, file_path):
        try: # TODO: Read file in chunks, Process, Update progress
            async with aiofiles.open(file_path, 'r') as f:
                pass
        except Exception as e:
            print(f"Error processing {file_path}: {e}")

    async def track_progress(self):
        while True: # TODO: Display progress for all files
            await asyncio.sleep(0.5) # TODO: Break when all complete
            pass

    async def process_all(self): # TODO: Run all tasks concurrently
        tasks = [self.process_file(fp) for fp in self.file_paths]
        progress_task = asyncio.create_task(self.track_progress())
        pass

# processor = ConcurrentFileProcessor(file_list)
# asyncio.run(processor.process_all())
```

# Conclusion & Best Practices

- Follow PEP 8 style guide
- Write readable, self-documenting code
- Use type hints for clarity
- Test your code thoroughly
- Handle exceptions appropriately
- Document with docstrings
- Use virtual environments
- Version control with Git

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# Further Learning Resources

- Home page – http://www.python.org
- Wiki – http://wiki.python.org/
- Packages – https://pypi.python.org/pypi
- Projects at http://sourceforge.net and github.org
- Real Python tutorials
- Python Package Index (PyPI)
- Stack Overflow community
- GitHub open source projects
- Python Enhancement Proposals (PEPs)
- Online courses and certifications

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# Data Structures and Algorithms

# Course Overview

- Fundamental Data Structures
- Core Algorithms & Techniques
- Time & Space Complexity Analysis
- 8 Essential LeetCode Patterns
- Real-world Problem Solving
- Best Practices & Optimization

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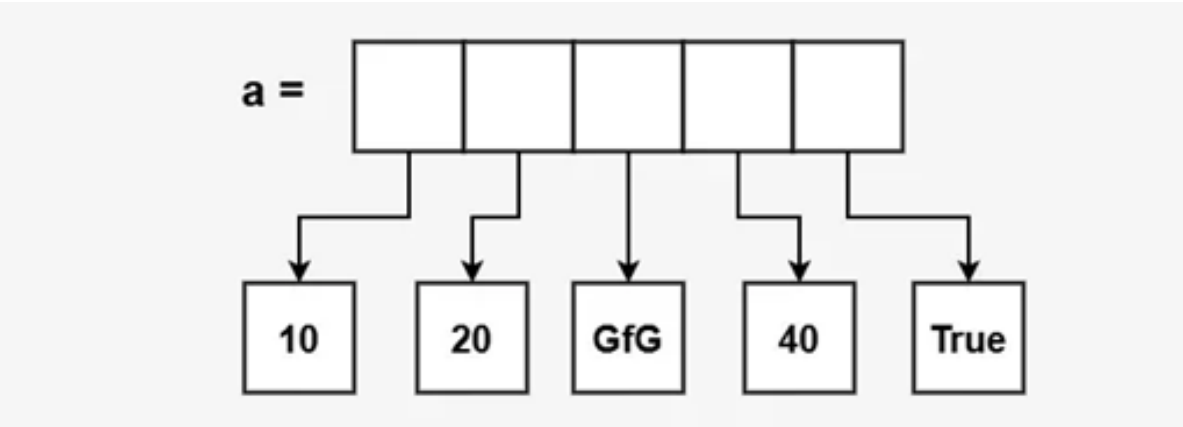
# Arrays & Lists - Fundamentals

- Dynamic arrays in Python (lists)
- O(1) access by index
- O(n) insertion/deletion (worst case)
- Contiguous memory allocation
- Common operations: append, insert, remove




(Ref: https://www.geeksforgeeks.org/python/python-lists/)

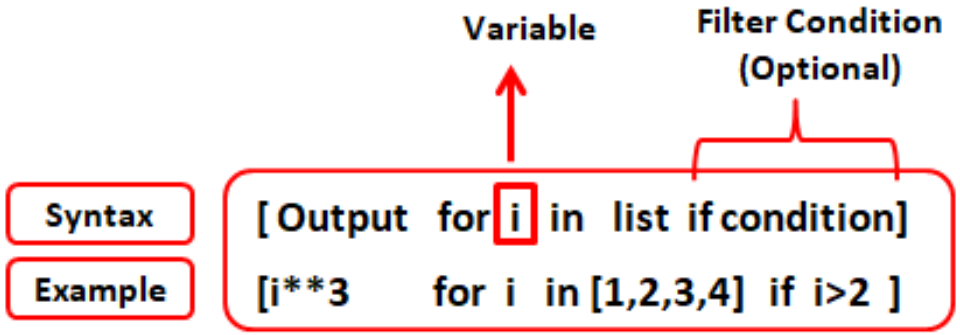
```python
# List creation
arr = [1, 2, 3, 4, 5]

# Access — O(1)
print(arr[0])  # 1

# Append — O(1) amortized
arr.append(6)

# Insert — O(n)
arr.insert(0, 0)

# Delete — O(n)
arr.remove(3)

# Slicing
sub = arr[1:4]
```

YHK

# List Comprehensions & Advanced Operations

- Pythonic way to create lists
- More readable and faster
- Supports filtering and mapping
- Can handle nested structures
- Essential for interview coding

```python
# Basic comprehension
squares = [x**2 for x in range(10)]

# With condition
evens = [x for x in range(20) if x % 2 == 0]

# Nested comprehension
matrix = [[i*j for j in range(3)]
          for i in range(3)]

# Map-like operation
names = ['alice', 'bob']
upper = [n.upper() for n in names]

# Filter and transform
nums = [1, -2, 3, -4]
positive_sq = [x**2 for x in nums if x > 0]
```

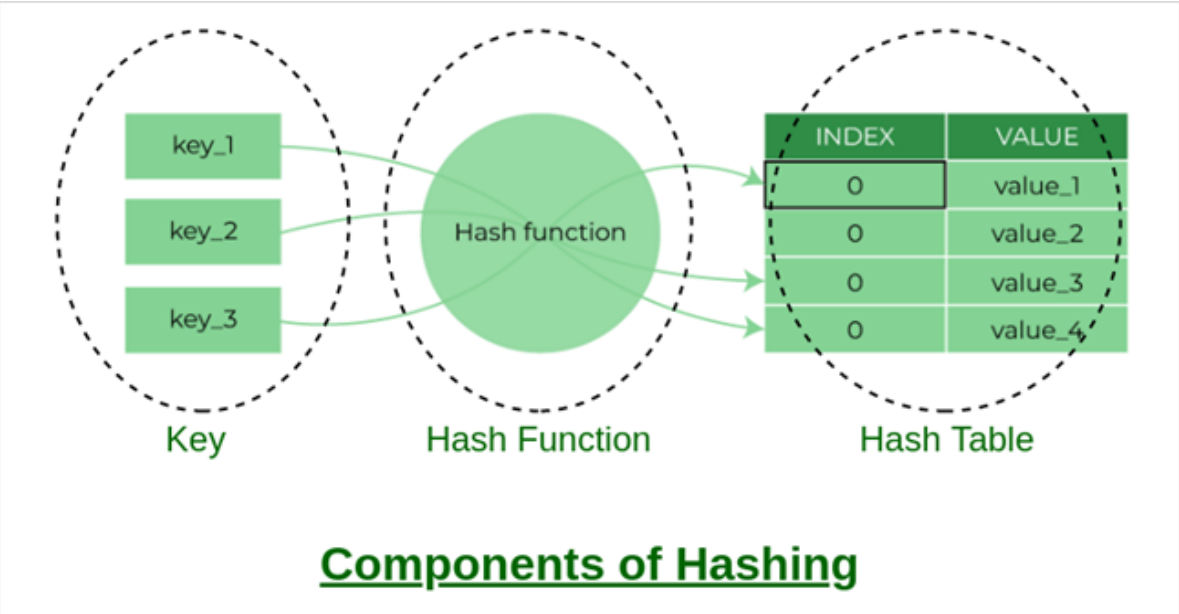



(Ref: https://www.listendata.com/2019/07/python-list-comprehension-with-examples.html)

YHK

# Hash Tables & Dictionaries

- O(1) average lookup, insert, delete
- Key-value pairs storage
- Hash function maps keys to indices
- Handles collisions internally
- Most versatile data structure




```python
# Dictionary creation
d = {'a': 1, 'b': 2}

# Access — O(1)
val = d.get('a', 0)  # Safe access

# Insert/Update — O(1)
d['c'] = 3

# Delete — O(1)
del d['b']

# Check existence
if 'a' in d:
    print(d['a'])

# Iterate
for key, val in d.items():
    print(f"{key}: {val}")

# defaultdict for cleaner code
from collections import defaultdict
count = defaultdict(int)
count['apple'] += 1

```

(Ref: https://www.listendata.com/2019/07/python-list-comprehension-with-examples.html)

YHK

# Sets - Unique Collections

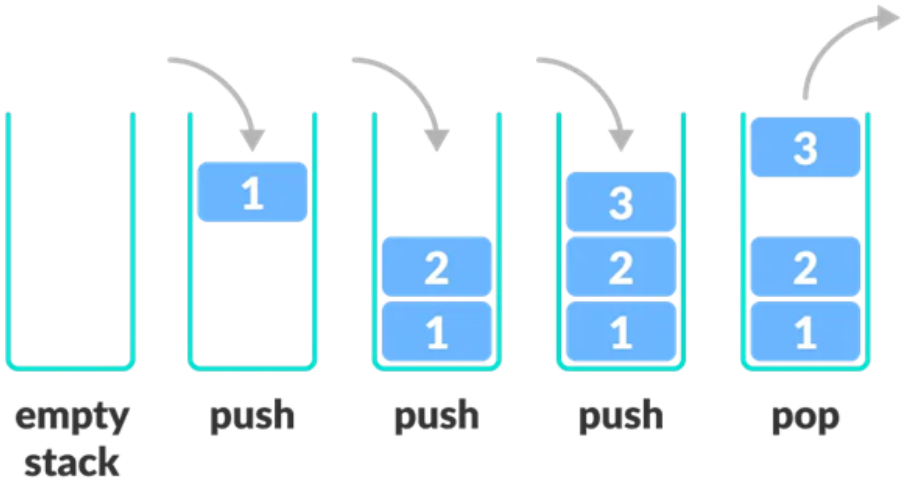
- Unordered collection of unique items
- O(1) membership testing
- Efficient set operations (union, intersection)
- No duplicate elements
- Useful for deduplication

```python
# Set creation
s = {1, 2, 3, 4}
s = set([1, 2, 2, 3])  # {1, 2, 3}

# Add - O(1)
s.add(5)

# Remove - O(1)
s.discard(2)  # Safe remove
s.remove(3)   # Raises error if not found

# Membership - O(1)
if 4 in s:
    print("Found")

# Set operations
a = {1, 2, 3}
b = {3, 4, 5}
union = a | b        # {1,2,3,4,5}
intersection = a & b # {3}
difference = a - b   # {1,2}

```

YHK

# Stacks - LIFO Structure

- Last In First Out (LIFO) principle
- O(1) push and pop operations
- Used in recursion, parsing, backtracking
- Python list works perfectly as stack
- Common uses: expression evaluation, DFS




(Ref: https://www.programiz.com/dsa/stack)

```python
# Stack using list
stack = []

# Push – O(1)
stack.append(1)
stack.append(2)
stack.append(3)

# Pop – O(1)
top = stack.pop()  # 3

# Peek
if stack:
    top = stack[-1]  # Don't remove

# Check if empty
is_empty = len(stack) == 0

# Valid Parentheses example
def isValid(s):
    stack = []
    pairs = {'(':')', '[':']', '{':'}'}
    for char in s:
        if char in pairs:
            stack.append(char)
        elif not stack or pairs[stack.pop()] != char:
            return False
    return len(stack) == 0

```

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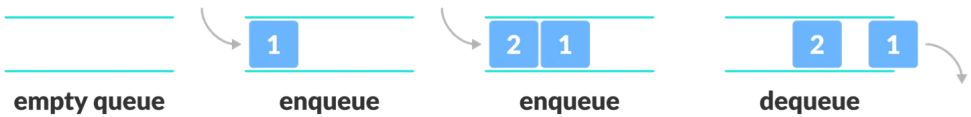
# Queues - FIFO Structure

- First In First Out (FIFO) principle
- O(1) enqueue and dequeue with deque
- Used in BFS, scheduling, buffering
- collections.deque is optimal
- Supports operations at both ends




(Ref: https://www.programiz.com/dsa/queue)

```python
from collections import deque

# Queue using deque
queue = deque()

# Enqueue – O(1)
queue.append(1)
queue.append(2)
queue.append(3)

# Dequeue – O(1)
first = queue.popleft()  # 1

# Peek front
if queue:
    front = queue[0]

# Peek back
if queue:
    back = queue[-1]

# BFS example
def bfs(graph, start):
    visited = set()
    queue = deque([start])
    while queue:
        node = queue.popleft()
        if node not in visited:
            visited.add(node)
            queue.extend(graph[node])
    return visited
```

YHK

# Linked Lists - Dynamic Structure

- Nodes connected via pointers
- O(1) insertion/deletion at known position
- O(n) search and access
- No contiguous memory required
- Types: singly, doubly, circular

```python
# Node definition
class ListNode:
    def __init__(self, val=0, next=None):
        self.val = val
        self.next = next

# Create linked list
head = ListNode(1)
head.next = ListNode(2)
head.next.next = ListNode(3)

# Traverse
curr = head
while curr:
    print(curr.val)
    curr = curr.next

# Reverse linked list
def reverseList(head):
    prev = None
    curr = head
    while curr:
        next_temp = curr.next
        curr.next = prev
        prev = curr
        curr = next_temp
    return prev
```

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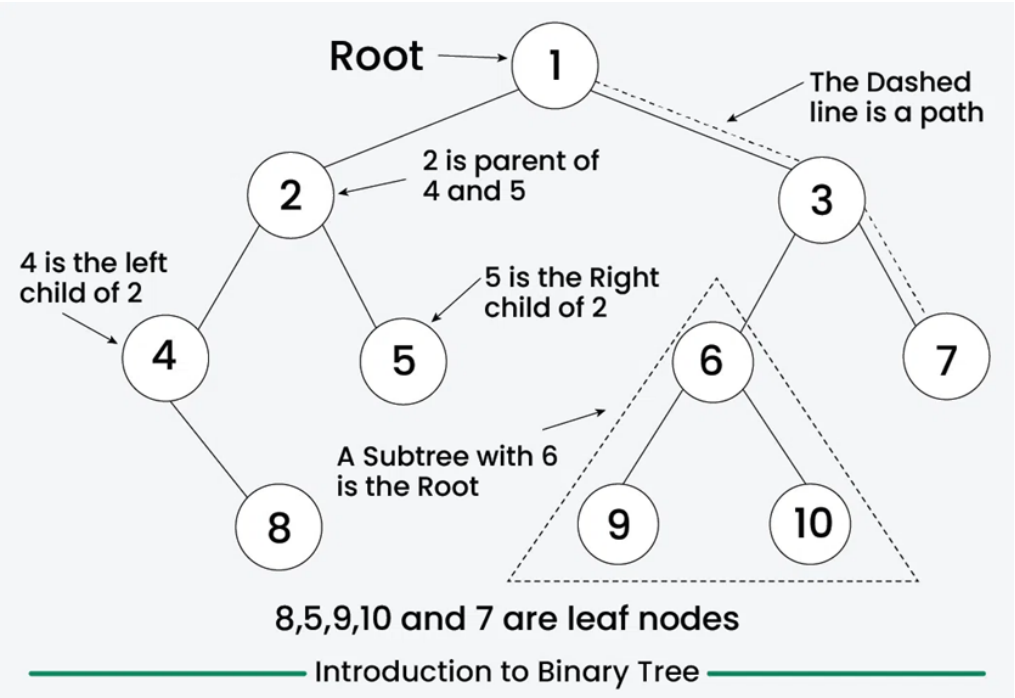
# Binary Trees - Hierarchical Structure

- Each node has at most 2 children
- Root, internal nodes, and leaves
- Traversals: inorder, preorder, postorder
- Height: O(log n) balanced, O(n) worst
- Foundation for BST, heaps, etc.




(Ref: https://www.geeksforgeeks.org/python/binary-tree-in-python/)

```python
# Tree node definition
class TreeNode:
    def __init__(self, val=0, left=None, right=None):
        self.val = val
        self.left = left
        self.right = right

# Inorder traversal (Left–Root–Right)
def inorder(root):
    if not root:
        return []
    return (inorder(root.left) +
            [root.val] +
            inorder(root.right))

# Level order traversal (BFS)
def levelOrder(root):
    if not root:
        return []
    result, queue = [], deque([root])
    while queue:
        level = []
        for _ in range(len(queue)):
            node = queue.popleft()
            level.append(node.val)
            if node.left:
                queue.append(node.left)
            if node.right:
                queue.append(node.right)
        result.append(level)
    return result
```

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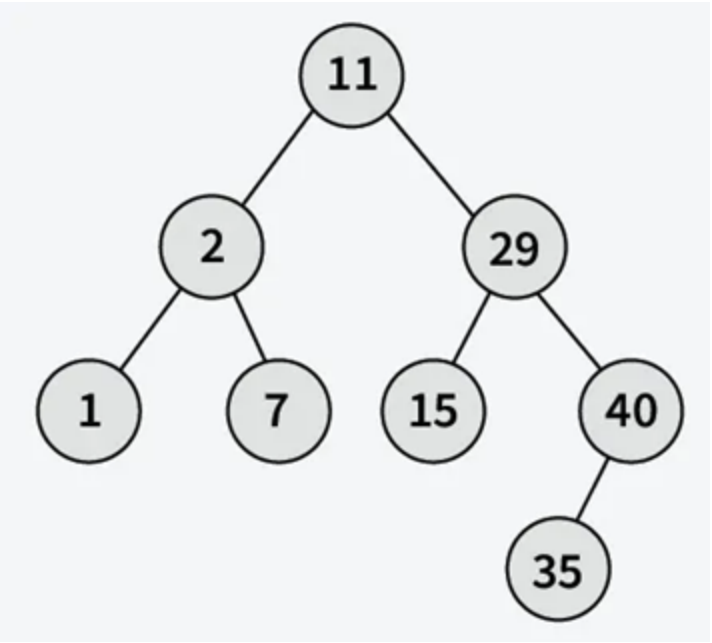
# Binary Search Trees (BST)

- Left subtree ¡ root ¡ right subtree
- O(log n) search, insert, delete (balanced)
- O(n) worst case (skewed tree)
- Inorder traversal gives sorted order
- Self-balancing variants: AVL, Red-Black




(Ref: https://www.geeksforgeeks.org/dsa/introduction-to-binary-search-tree/)

```python
# Search in BST
def searchBST(root, val):
    if not root or root.val == val:
        return root
    if val < root.val:
        return searchBST(root.left, val)
    return searchBST(root.right, val)

# Insert into BST
def insertBST(root, val):
    if not root:
        return TreeNode(val)
    if val < root.val:
        root.left = insertBST(root.left, val)
    else:
        root.right = insertBST(root.right, val)
    return root

# Validate BST
def isValidBST(root, min_val=float('-inf'),
               max_val=float('inf')):
    if not root:
        return True
    if not (min_val < root.val < max_val):
        return False
    return (isValidBST(root.left, min_val, root.val)
            and
            isValidBST(root.right, root.val, max_val))
```

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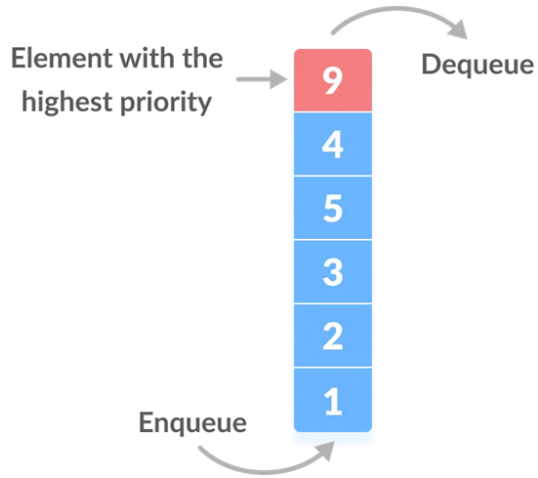
# Heaps & Priority Queues

- Complete binary tree structure
- Min-heap: parent $\leq$ children
- Max-heap: parent $\geq$ children
- O(log n) insert and extract-min/max
- O(1) peek at min/max element
- Used in: Dijkstra, heap sort, scheduling




```python
import heapq

# Min heap (default in Python)
heap = []
heapq.heappush(heap, 5)
heapq.heappush(heap, 2)
heapq.heappush(heap, 8)

# Extract min - O(log n)
min_val = heapq.heappop(heap)  # 2

# Peek min - O(1)
if heap:
    min_val = heap[0]

# Heapify array - O(n)
arr = [5, 2, 8, 1, 9]
heapq.heapify(arr)

# Max heap (negate values)
max_heap = []
heapq.heappush(max_heap, -5)
max_val = -heapq.heappop(max_heap)

# K largest elements
def kLargest(nums, k):
    return heapq.nlargest(k, nums)
```

(Ref: https://www.geeksforgeeks.org/dsa/introduction-to-binary-search-tree/)

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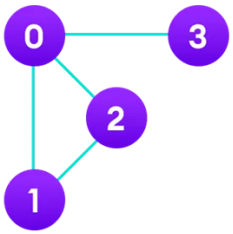
# Graphs - Representation

- Vertices (nodes) and edges (connections)
- Directed vs undirected
- Weighted vs unweighted
- Adjacency list: O(V+E) space
- Adjacency matrix: $O(V^2)$ space
- Most problems use adjacency list




| | 0 | 1 | 2 | 3 |
|---|---|---|---|---|
| 0 | 0 | 1 | 1 | 1 |
| 1 | 1 | 0 | 1 | 0 |
| 2 | 1 | 1 | 0 | 0 |
| 3 | 1 | 0 | 0 | 0 |

(Ref: https://www.programiz.com/dsa/graph)

```python
from collections import defaultdict

# Adjacency list representation
graph = defaultdict(list)

# Add edge (undirected)
def add_edge(u, v):
    graph[u].append(v)
    graph[v].append(u)

# Add weighted edge
weighted_graph = defaultdict(list)
def add_weighted_edge(u, v, w):
    weighted_graph[u].append((v, w))
    weighted_graph[v].append((u, w))

# Example graph
add_edge(0, 1)
add_edge(0, 2)
add_edge(1, 2)
add_edge(2, 3)

# Adjacency matrix (for dense graphs)
n = 4
matrix = [[0]*n for _ in range(n)]
matrix[0][1] = matrix[1][0] = 1
```

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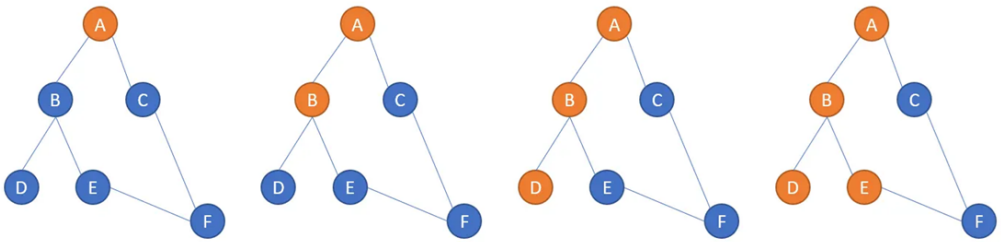
# Graph Traversals - DFS

- DFS: Depth First Search (stack/recursion)
- BFS: Breadth First Search (queue)
- $O(V + E)$ time complexity
- DFS for: cycles, topological sort, paths




(Ref: DFS https://medium.com/nerd-for-tech/graph-traversal-in-python-depth-first-search-dfs-ce791f48af5b)

```python
# DFS – Recursive
def dfs(graph, node, visited=None):
    if visited is None:
        visited = set()
    visited.add(node)
    print(node)
    for neighbor in graph[node]:
        if neighbor not in visited:
            dfs(graph, neighbor, visited)
    return visited

# DFS – Iterative
def dfs_iterative(graph, start):
    visited = set()
    stack = [start]
    while stack:
        node = stack.pop()
        if node not in visited:
            visited.add(node)
            print(node)
            stack.extend(graph[node])
    return visited
```

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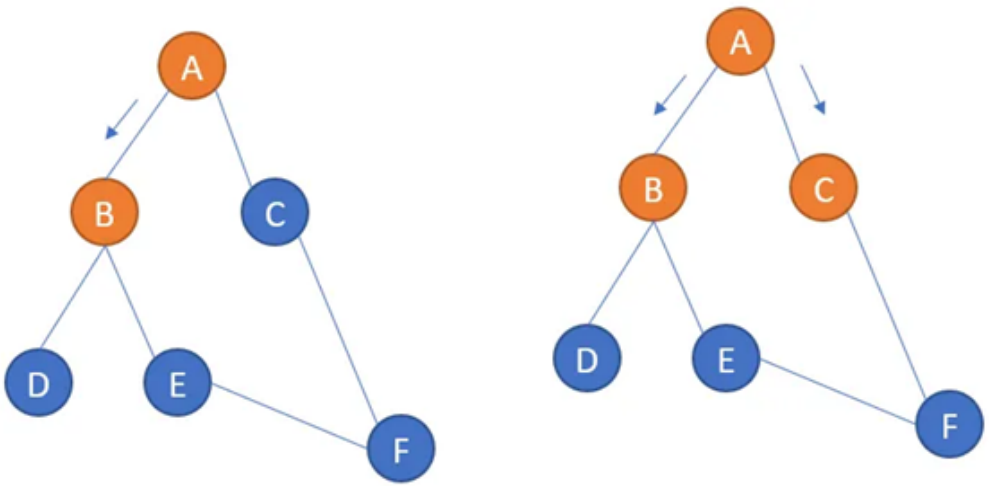
# Graph Traversals - BFS

- BFS: Breadth First Search (queue)
- $O(V + E)$ time complexity
- BFS for: shortest path, level-order




(Ref: BFS https://medium.com/nerd-for-tech/graph-traversal-in-python-breadth-first-search-bfs-b6cff138d516)

```python
# BFS
def bfs(graph, start):
    visited = set([start])
    queue = deque([start])
    while queue:
        node = queue.popleft()
        print(node)
        for neighbor in graph[node]:
            if neighbor not in visited:
                visited.add(neighbor)
                queue.append(neighbor)
    return visited
```

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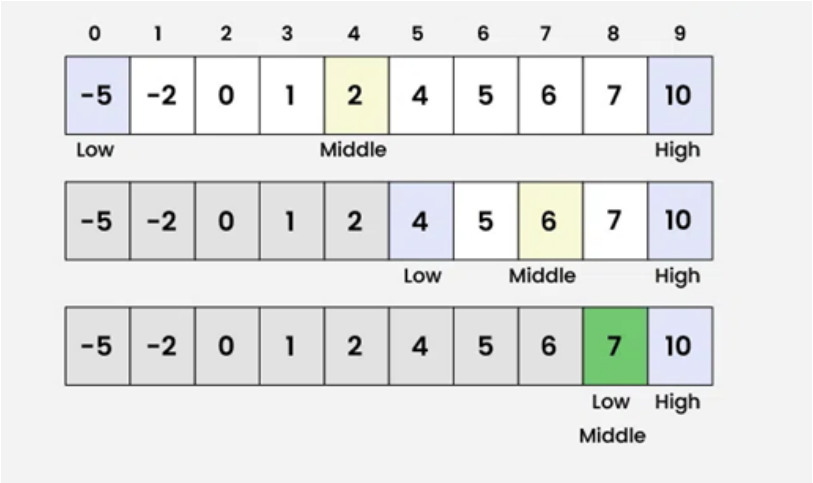
# Binary Search Algorithm

- O(log n) search in sorted array
- Divide and conquer approach
- Eliminates half of elements each step
- Must have sorted input
- Template applicable to many problems
- Find exact match or insertion point



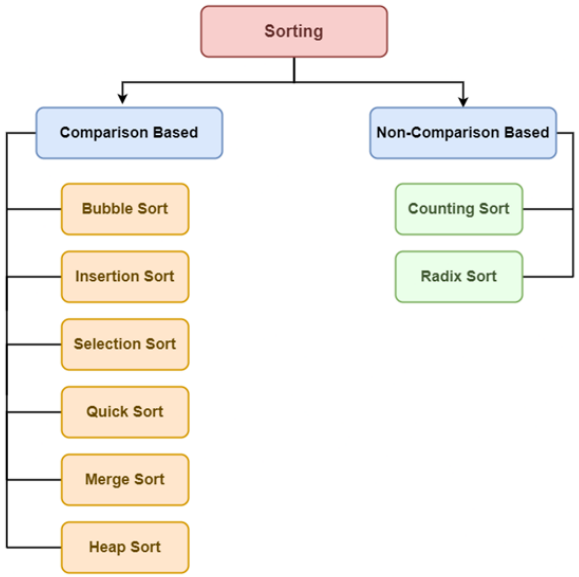

(Ref: BFS https://medium.com/nerd-for-tech/graph-traversal-in-python-breadth-first-search-bfs-b6cff138d516)

```python
# Standard binary search
def binary_search(arr, target):
    left, right = 0, len(arr) - 1
    while left <= right:
        mid = left + (right - left) // 2
        if arr[mid] == target: return mid
        elif arr[mid] < target:
            left = mid + 1
        else: right = mid - 1
    return -1

# Find insertion position
def searchInsert(nums, target):
    left, right = 0, len(nums)
    while left < right:
        mid = left + (right - left) // 2
        if nums[mid] < target: left = mid + 1
        else: right = mid
    return left

# Find first occurrence
def findFirst(arr, target):
    left, right = 0, len(arr) - 1
    result = -1
    while left <= right:
        mid = left + (right - left) // 2
        if arr[mid] == target:
            result = mid
            right = mid - 1
        elif arr[mid] < target: left = mid + 1
        else: right = mid - 1
    return result
```

YHK

# Sorting Algorithms - Comparison Based

- Quick Sort: O(n log n) avg, $O(n^2)$ worst
- Merge Sort: O(n log n) guaranteed
- Heap Sort: O(n log n), in-place
- Bubble/Insertion: $O(n^2)$, simple
- Python's sorted() uses Timsort




(Ref: https://www.geeksforgeeks.org/dsa/introduction-to-sorting-algorithm/)

```python
# Quick Sort
def quicksort(arr):
    if len(arr) <= 1:
        return arr
    pivot = arr[len(arr) // 2]
    left = [x for x in arr if x < pivot]
    middle = [x for x in arr if x == pivot]
    right = [x for x in arr if x > pivot]
    return quicksort(left) + middle + quicksort(right)

# Merge Sort
def mergesort(arr):
    if len(arr) <= 1:
        return arr
    mid = len(arr) // 2
    left = mergesort(arr[:mid])
    right = mergesort(arr[mid:])
    return merge(left, right)

def merge(left, right):
    result = []
    i = j = 0
    while i < len(left) and j < len(right):
        if left[i] <= right[j]:
            result.append(left[i])
            i += 1
        else:
            result.append(right[j])
            j += 1
    result.extend(left[i:])
    result.extend(right[j:])
    return result
```

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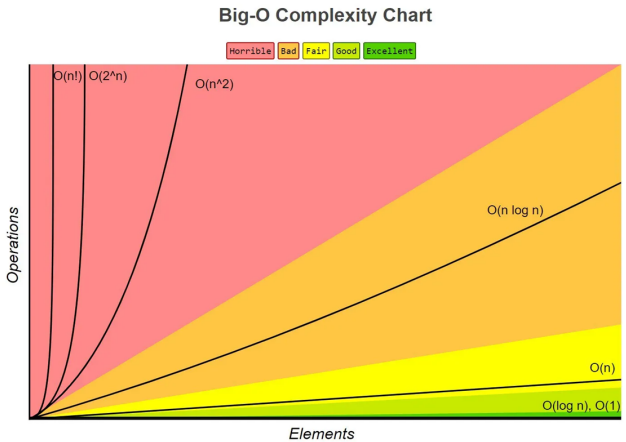
# Big O Notation - Time & Space Complexity

- Measures algorithm efficiency
- $O(1)$: Constant time
- $O(logn)$: Logarithmic (binary search)
- $O(n)$: Linear (single loop)
- $O(nlogn)$: Linearithmic (merge sort)
- $O(n^2)$: Quadratic (nested loops)
- $O(2^n)$: Exponential (recursion)
- Drop constants and lower order terms

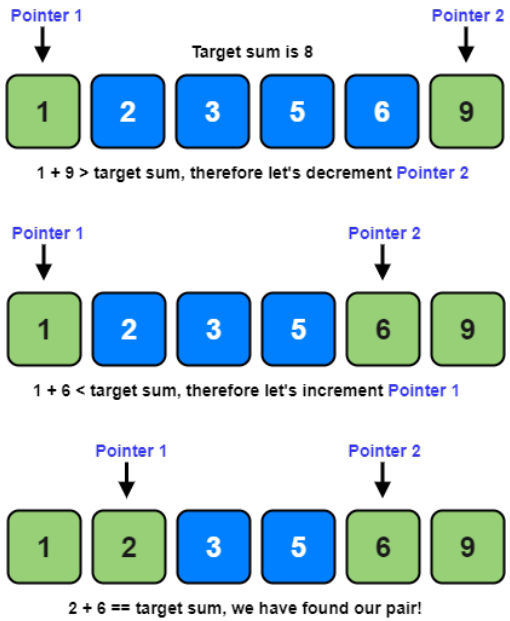



```python
def get_first(arr): # O(1) — Constant
    return arr[0]

def find_max(arr): # O(n) — Linear
    max_val = arr[0]
    for num in arr:
        if num > max_val: max_val = num
    return max_val

def bubble_sort(arr): # O(n^2) — Quadratic
    n = len(arr)
    for i in range(n):
        for j in range(n-i-1):
            if arr[j] > arr[j+1]:
                arr[j], arr[j+1] = arr[j+1], arr[j]

# O(log n) — Logarithmic
def binary_search(arr, target):
    left, right = 0, len(arr)-1
    while left <= right:
        mid = (left + right) // 2
        if arr[mid] == target:
            return mid
        elif arr[mid] < target: left = mid + 1
        else: right = mid - 1
    return -1

def fibonacci(n): # O(2^n) — Exponential
    if n <= 1: return n
    return fibonacci(n-1) + fibonacci(n-2)
```

(Ref: https://medium.com/data-science/understanding-time-complexity-with-python-

# Pattern 1: Two Pointers Technique

- Use two pointers to iterate array
- Opposite direction or same direction
- O(n) time, O(1) space typically
- Common in: sorted arrays, palindromes
- Example: Two Sum II, Container With Most Water



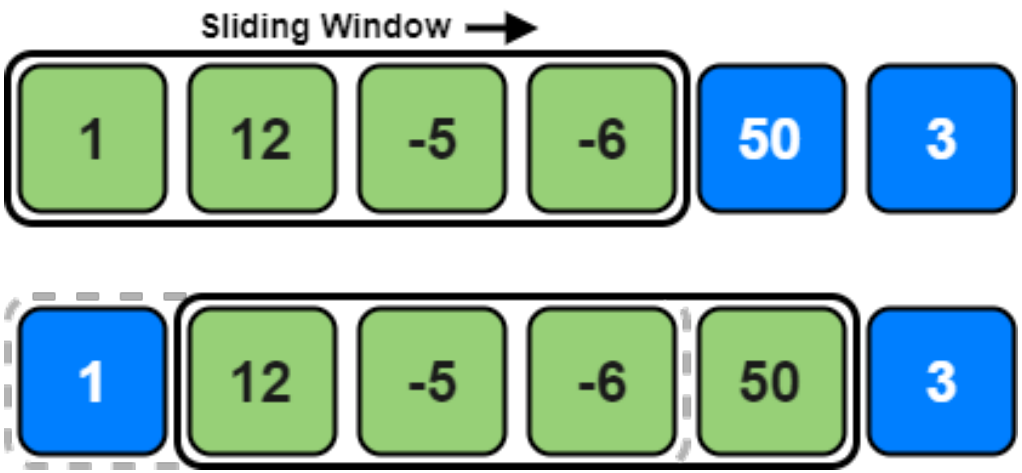

(Ref: https://emre.me/coding-patterns/two-pointers/)

```python
# Problem: Two Sum II (sorted array)
# Given sorted array, find two numbers
# that add up to target
def twoSum(numbers, target):
    left, right = 0, len(numbers) - 1
    while left < right:
        curr_sum = numbers[left] + numbers[right]
        if curr_sum == target:
            return [left + 1, right + 1]
        elif curr_sum < target:
            left += 1
        else:
            right -= 1
    return []

# Problem: Valid Palindrome
def isPalindrome(s):
    left, right = 0, len(s) - 1
    while left < right:
        while left < right and not s[left].isalnum():
            left += 1
        while left < right and not s[right].isalnum():
            right -= 1
        if s[left].lower() != s[right].lower():
            return False
        left += 1
        right -= 1
    return True
```

YHK

# Pattern 2: Sliding Window

- Fixed or variable size window
- Maintains window state efficiently
- O(n) time for array/string problems
- Common in: subarray/substring problems
- Example: Max Sum Subarray, Longest Substring




(Ref: https://emre.me/coding-patterns/sliding-window/)

```python
# Problem: Max Sum of Subarray of Size K
def maxSumSubarray(arr, k):
    if len(arr) < k:
        return 0

    # Calculate sum of first window
    window_sum = sum(arr[:k])
    max_sum = window_sum

    # Slide window
    for i in range(k, len(arr)):
        window_sum = window_sum - arr[i-k] +
            arr[i]
        max_sum = max(max_sum, window_sum)

    return max_sum

# Problem: Longest Substring Without Repeating
def lengthOfLongestSubstring(s):
    char_set = set()
    left = 0
    max_len = 0

    for right in range(len(s)):
        while s[right] in char_set:
            char_set.remove(s[left])
            left += 1
        char_set.add(s[right])
        max_len = max(max_len, right - left + 1)

    return max_len
```

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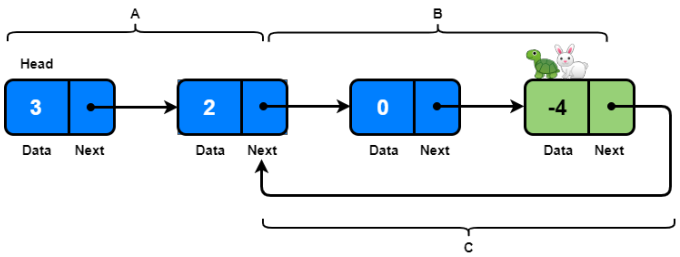
# Pattern 3: Fast & Slow Pointers (Floyd's Cycle)

- Two pointers moving at different speeds
- Detects cycles in linked lists
- Finds middle element efficiently
- O(n) time, O(1) space
- Example: Linked List Cycle, Happy Number




(Ref: https://emre.me/coding-patterns/fast-slow-pointers/)

```python
def hasCycle(head): # Problem: Detect Cycle in Linked List
    if not head or not head.next: return False
    slow = head
    fast = head.next
    while slow != fast:
        if not fast or not fast.next: return False
        slow = slow.next
        fast = fast.next.next
    return True

def middleNode(head): # Problem: Find Middle of Linked List
    slow = fast = head
    while fast and fast.next:
        slow = slow.next
        fast = fast.next.next
    return slow

def isHappy(n): # Problem: Happy Number
    def get_next(num):
        total = 0
        while num > 0:
            digit = num % 10
            total += digit ** 2
            num //= 10
        return total
    slow = n
    fast = get_next(n)
    while fast != 1 and slow != fast:
        slow = get_next(slow)
        fast = get_next(get_next(fast))
    return fast == 1

```

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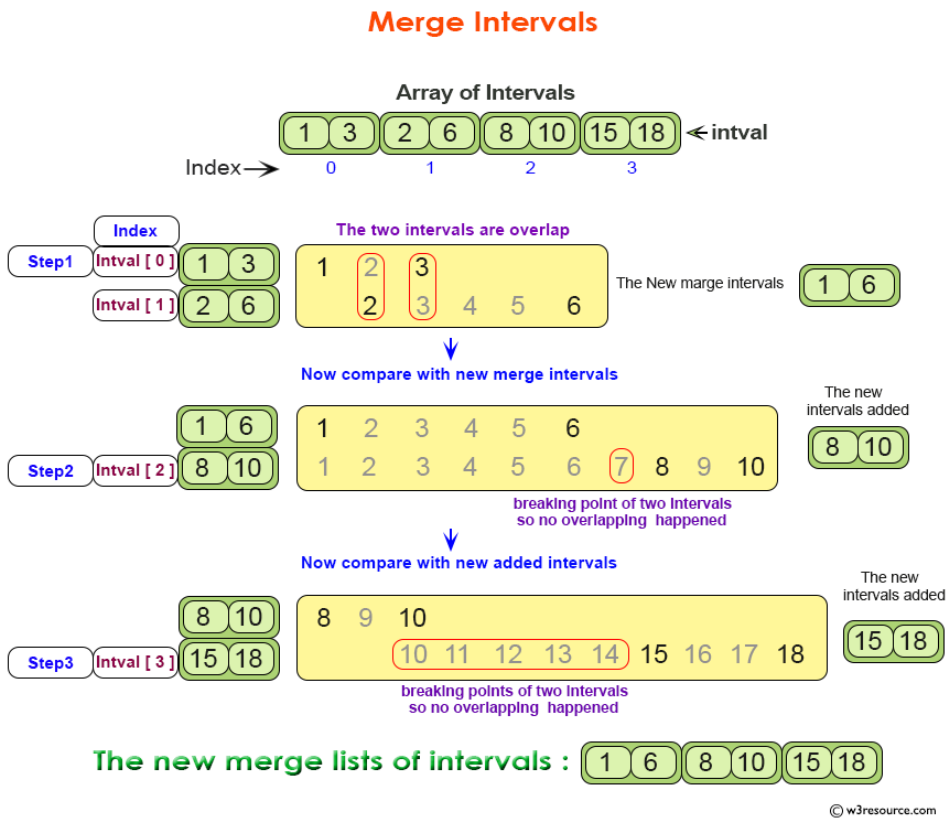
# Pattern 4: Merge Intervals

- Sort intervals by start time
- Merge overlapping intervals
- O(n log n) time due to sorting
- Common in: scheduling, ranges
- Example: Merge Intervals, Insert Interval




(Ref: https://www.w3resource.com/data-structures-and-algorithms/array/dsa-merge-intervals.php)

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# Pattern 4: Merge Intervals

```python
# Problem: Merge Overlapping Intervals
def merge(intervals):
    if not intervals:
        return []

    # Sort by start time
    intervals.sort(key=lambda x: x[0])
    merged = [intervals[0]]

    for current in intervals[1:]:
        last = merged[-1]
        if current[0] <= last[1]:
            # Overlapping, merge
            last[1] = max(last[1], current[1])
        else:
            # Non-overlapping, add
            merged.append(current)

    return merged
```

```python
# Problem: Insert Interval
def insert(intervals, newInterval):
    result = []
    i = 0
    n = len(intervals)

    # Add all intervals before newInterval
    while i < n and intervals[i][1] < newInterval[0]:
        result.append(intervals[i])
        i += 1

    # Merge overlapping intervals
    while i < n and intervals[i][0] <= newInterval[1]:
        newInterval[0] = min(newInterval[0], intervals[i][0])
        newInterval[1] = max(newInterval[1], intervals[i][1])
        i += 1
    result.append(newInterval)

    # Add remaining intervals
    result.extend(intervals[i:])
    return result
```

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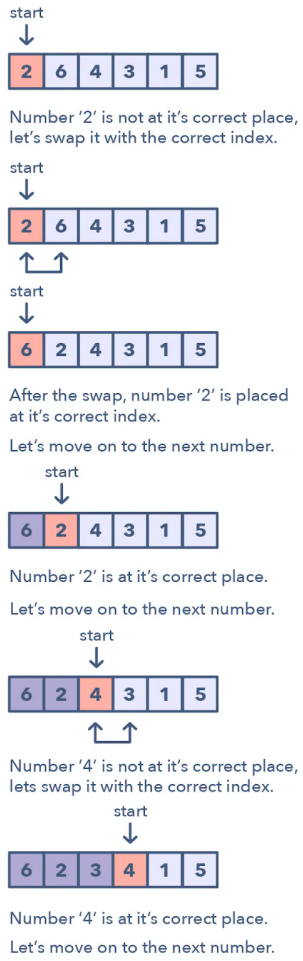
# Pattern 5: Cyclic Sort

- For arrays with numbers in range [1, n]
- Place each number at its correct index
- O(n) time, O(1) space
- Finds missing/duplicate numbers
- Example: Find Missing Number, First Missing Positive




(Ref: paulonteri/data-structures-and-algorithms)

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# Pattern 5: Cyclic Sort

```python
# Problem: Find Missing Number (0 to n)
def missingNumber(nums):
    i = 0
    n = len(nums)

    while i < n:
        correct_idx = nums[i]
        if nums[i] < n and nums[i] != nums[correct_idx]:
            # Swap to correct position
            nums[i], nums[correct_idx] = nums[correct_idx], nums[i]
        else:
            i += 1

    # Find first missing
    for i in range(n):
        if nums[i] != i:
            return i
    return n
```

```python
# Problem: Find All Duplicates (1 to n)
def findDuplicates(nums):
    i = 0
    while i < len(nums):
        correct_idx = nums[i] - 1
        if nums[i] != nums[correct_idx]:
            nums[i], nums[correct_idx] =
            nums[correct_idx], nums[i]
        else:
            i += 1

    duplicates = []
    for i in range(len(nums)):
        if nums[i] != i + 1:
            duplicates.append(nums[i])

    return duplicates

```

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# Pattern 6: In-place Reversal of Linked List

- Reverse links without extra space
- Three pointers: prev, curr, next
- O(n) time, O(1) space
- Fundamental for many LL problems
- Example: Reverse Linked List, Reverse in K-Group

```python
# Problem: Reverse Linked List
def reverseList(head):
    prev = None
    curr = head

    while curr:
        next_temp = curr.next
        curr.next = prev
        prev = curr
        curr = next_temp

    return prev

```

```python
# Problem: Reverse Linked List II
# (from position left to right)
def reverseBetween(head, left, right):
    if not head or left == right:
        return head

    dummy = ListNode(0)
    dummy.next = head
    prev = dummy

    # Move to position before left
    for _ in range(left - 1):
        prev = prev.next

    # Reverse from left to right
    curr = prev.next
    for _ in range(right - left):
        next_temp = curr.next
        curr.next = next_temp.next
        next_temp.next = prev.next
        prev.next = next_temp

    return dummy.next

```

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# Pattern 7: Tree BFS (Level Order Traversal)

- Use queue for level-by-level traversal
- Process nodes at same level together
- O(n) time, O(w) space (w = max width)
- Example: Level Order, Zigzag Traversal

```python
from collections import deque

# Problem: Binary Tree Level Order Traversal
def levelOrder(root):
    if not root: return []

    result = []
    queue = deque([root])

    while queue:
        level_size = len(queue)
        current_level = []
        for _ in range(level_size):
            node = queue.popleft()
            current_level.append(node.val)

            if node.left: queue.append(node.left)
            if node.right: queue.append(node.right)

        result.append(current_level)

    return result
```

```python
# Problem: Zigzag Level Order Traversal
def zigzagLevelOrder(root):
    if not root: return []

    result = []
    queue = deque([root])
    left_to_right = True

    while queue:
        level = []
        for _ in range(len(queue)):
            node = queue.popleft()
            level.append(node.val)
            if node.left: queue.append(node.left)
            if node.right: queue.append(node.right)

        if not left_to_right: level.reverse()
        result.append(level)
        left_to_right = not left_to_right

    return result
```

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# Pattern 8: Tree DFS (Depth First Search)

- Recursion or stack for deep traversal
- Preorder, Inorder, Postorder variants
- O(n) time, O(h) space (h = height)
- Common in: path problems, subtree checks
- Example: Max Depth, Path Sum, Diameter

```python
# Problem: Maximum Depth of Binary Tree
def maxDepth(root):
    if not root:
        return 0
    left_depth = maxDepth(root.left)
    right_depth = maxDepth(root.right)
    return 1 + max(left_depth, right_depth)
```

```python
# Problem: Path Sum
def hasPathSum(root, targetSum):
    if not root:
        return False

    if not root.left and not root.right:
        return root.val == targetSum

    targetSum -= root.val
    return (hasPathSum(root.left, targetSum) or
            hasPathSum(root.right, targetSum))

# Problem: Diameter of Binary Tree
def diameterOfBinaryTree(root):
    diameter = 0

    def height(node):
        nonlocal diameter
        if not node:
            return 0

        left = height(node.left)
        right = height(node.right)
        diameter = max(diameter, left + right)

        return 1 + max(left, right)

    height(root)
    return diameter
```

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# Dynamic Programming - Foundations

- Break problem into overlapping subproblems
- Store solutions to avoid recomputation
- Top-down (memoization) or bottom-up (tabulation)
- Identify: optimal substructure + overlapping subproblems
- Example: Fibonacci, Climbing Stairs

```python
# Fibonacci — Naive (exponential)
def fib_naive(n):
    if n <= 1:
        return n
    return fib_naive(n-1) + fib_naive(n-2)
```

```python
# Fibonacci — Memoization (top-down)
def fib_memo(n, memo={}):
    if n in memo:
        return memo[n]
    if n <= 1:
        return n
    memo[n] = fib_memo(n-1, memo) + fib_memo(n-2, memo)
    return memo[n]

# Fibonacci — Tabulation (bottom-up)
def fib_tab(n):
    if n <= 1:
        return n
    dp = [0] * (n + 1)
    dp[1] = 1
    for i in range(2, n + 1):
        dp[i] = dp[i-1] + dp[i-2]
    return dp[n]

# Fibonacci — Space Optimized
def fib_optimal(n):
    if n <= 1:
        return n
    prev, curr = 0, 1
    for _ in range(2, n + 1):
        prev, curr = curr, prev + curr
    return curr
```

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# Dynamic Programming - Classic Problems

- Coin Change: min coins for amount
- Longest Common Subsequence (LCS)
- 0/1 Knapsack Problem
- House Robber variations
- Edit Distance

```python
# Problem: Coin Change
def coinChange(coins, amount):
    dp = [float('inf')] * (amount + 1)
    dp[0] = 0

    for coin in coins:
        for i in range(coin, amount + 1):
            dp[i] = min(dp[i], dp[i - coin] + 1)

    return dp[amount] if dp[amount] != float('inf') else -1
```

```python
# Problem: Longest Common Subsequence
def longestCommonSubsequence(text1, text2):
    m, n = len(text1), len(text2)
    dp = [[0] * (n + 1) for _ in range(m + 1)]

    for i in range(1, m + 1):
        for j in range(1, n + 1):
            if text1[i-1] == text2[j-1]:
                dp[i][j] = dp[i-1][j-1] + 1
            else:
                dp[i][j] = max(dp[i-1][j], dp[i][j-1])

    return dp[m][n]

# Problem: House Robber
def rob(nums):
    if not nums:
        return 0
    if len(nums) == 1:
        return nums[0]

    prev2, prev1 = 0, 0
    for num in nums:
        temp = prev1
        prev1 = max(prev2 + num, prev1)
        prev2 = temp

    return prev1
```

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# Backtracking - Exhaustive Search

- Try all possibilities recursively
- Prune invalid paths early
- Build solution incrementally
- Undo choices (backtrack) when needed
- Example: Permutations, Subsets, N-Queens

```python
# Problem: Generate All Subsets
def subsets(nums):
    result = []

    def backtrack(start, path):
        result.append(path[:])

        for i in range(start, len(nums)):
            path.append(nums[i])
            backtrack(i + 1, path)
            path.pop()  # Backtrack

    backtrack(0, [])
    return result
```

```python
# Problem: Permutations
def permute(nums):
    result = []

    def backtrack(path, remaining):
        if not remaining:
            result.append(path[:])
            return

        for i in range(len(remaining)):
            backtrack(path + [remaining[i]],
                      remaining[:i] + remaining[i+1:])

    backtrack([], nums)
    return result

# Problem: Combination Sum
def combinationSum(candidates, target):
    result = []
    def backtrack(start, path, total):
        if total == target:
            result.append(path[:])
            return
        if total > target:  return

        for i in range(start, len(candidates)):
            path.append(candidates[i])
            backtrack(i, path, total + candidates[i])
            path.pop()

    backtrack(0, [], 0)
    return result
```

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# Advanced Topics & Techniques

- Trie (Prefix Tree) for string problems
- Union-Find for connected components
- Topological Sort for DAGs
- Dijkstra's & Bellman-Ford for shortest paths
- Bit Manipulation tricks
- Greedy algorithms
- Monotonic Stack/Queue

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# Conclusion & Best Practices

- Start with brute force, then optimize
- Identify pattern before coding
- Draw diagrams for complex problems
- Test with edge cases
- Analyze time & space complexity
- Practice consistently on LeetCode
- Master the 8 common patterns
- Review and learn from solutions

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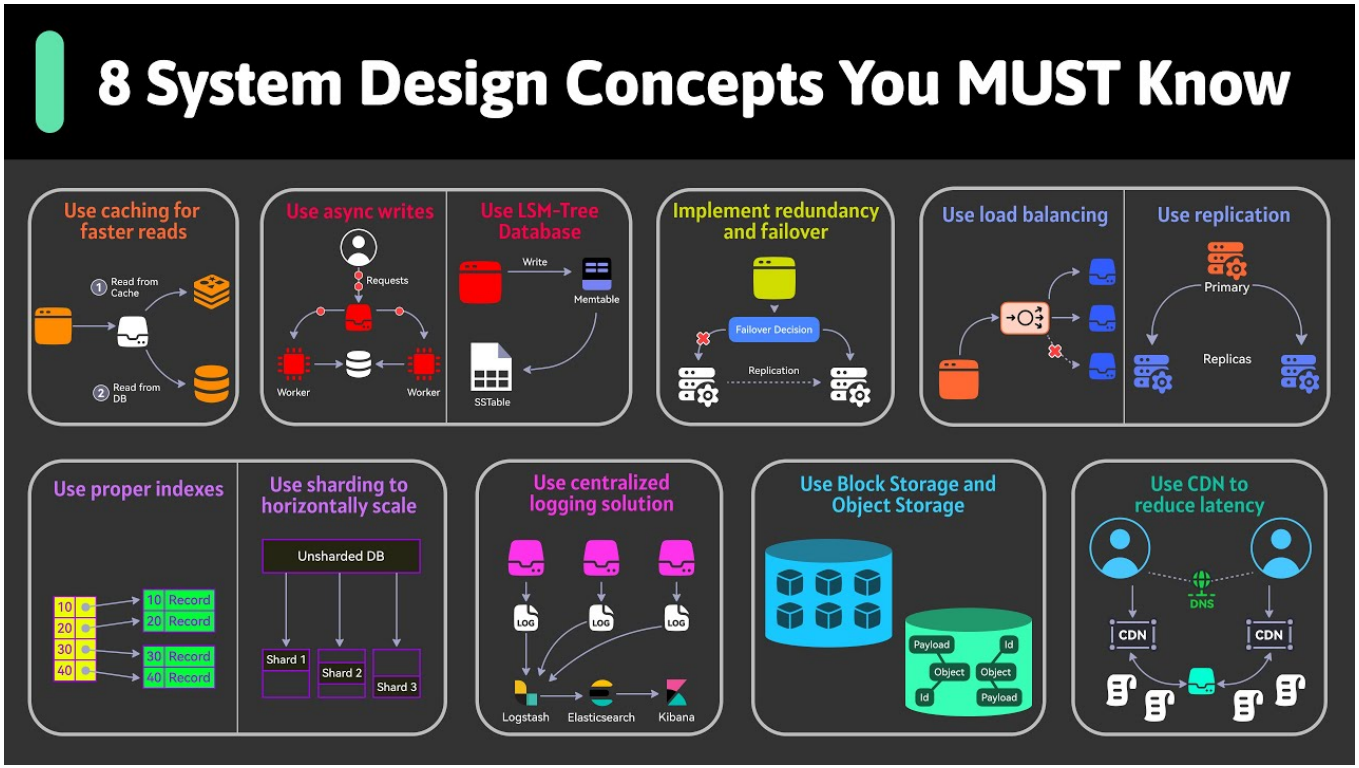
# System Design

# Why System Design?

- Comprehensive guide to system design concepts
- From fundamentals to Implementations
- Real-world scalability challenges




(Ref: https://www.youtube.com/watch?v=BTjxUS_PyIA)

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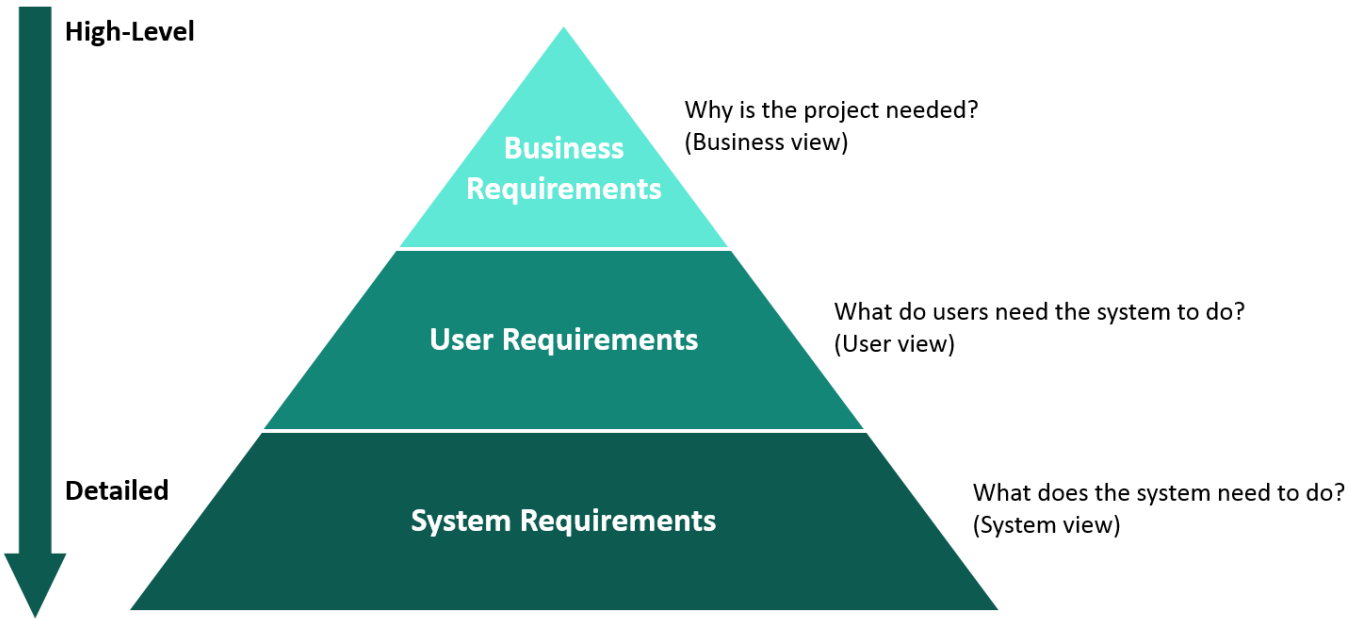
# Requirements Analysis: Foundation of Design

- **Functional Requirements**: What system should do (features, APIs, flows)
- **Non-Functional Requirements**: How system should perform (latency, availability, consistency)
- **Capacity Estimation**: Users, requests/sec, storage needs, bandwidth
- **Constraints**: Budget, timeline, existing infrastructure
- Always clarify ambiguities before diving into design




(Ref: http://www.crvs-dgb.org/en/activities/analysis-and-design/8-define-system-requirements/)

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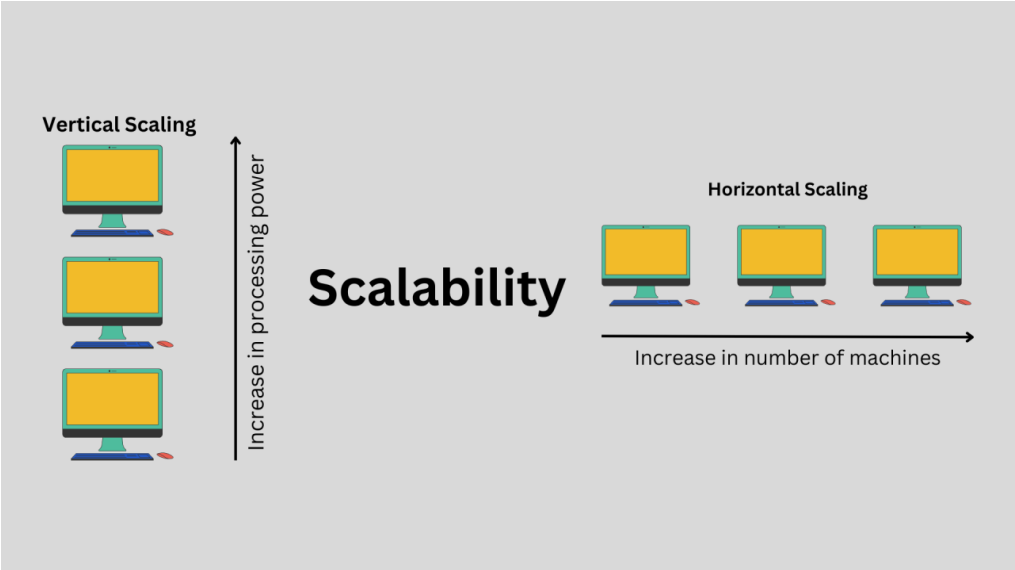
# Scalability: Growing Your System

- **Vertical Scaling**: Add more resources (CPU, RAM) to single machine - simple but limited
- **Horizontal Scaling**: Add more machines - unlimited growth, requires coordination
- **Stateless Services**: Enable easy horizontal scaling by removing server-side session state
- **Sharding/Partitioning**: Split data across multiple databases
- **Microservices**: Decompose monolith into independent, scalable services




(Ref: https://www.linkedin.com/pulse/system-design-horizontal-scaling-vs-vertical-harsh-kumar-sharma-jadpf/)

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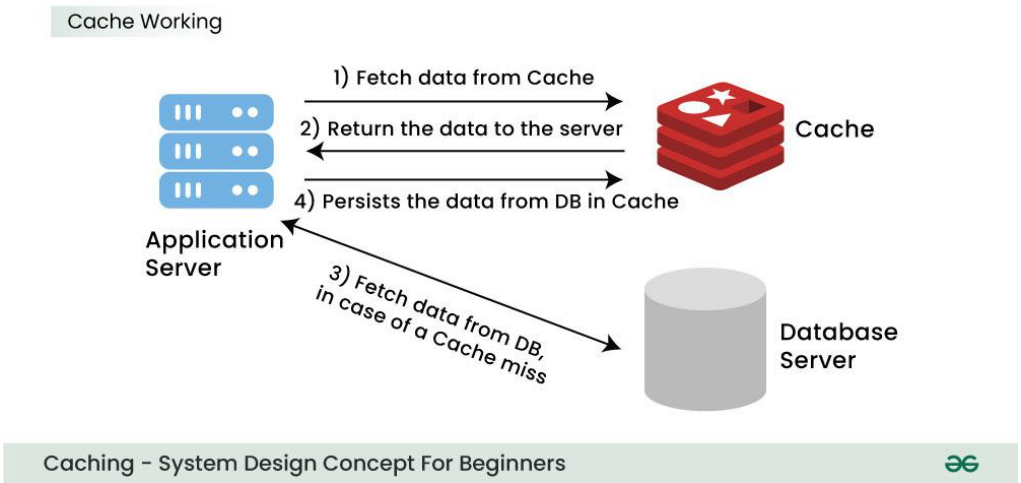
# Caching: Speed Through Memory

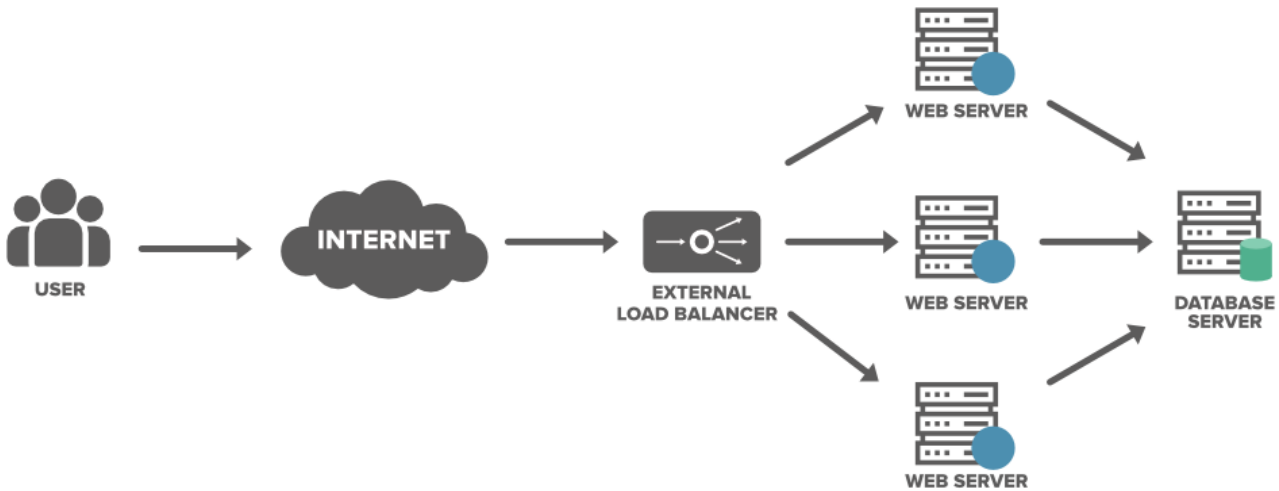
- **Cache-Aside**: App checks cache first, loads from DB on miss, updates cache
- **Write-Through**: Write to cache and DB simultaneously - consistent but slower writes
- **Write-Back**: Write to cache only, async persist to DB - fast but risk data loss
- **Eviction Policies**: LRU, LFU, FIFO for managing limited cache space
- **CDN**: Cache static content geographically close to users
- Tools: Redis, Memcached, Varnish




(Ref: https://www.geeksforgeeks.org/system-design/caching-system-design-concept-for-beginners/)

# Load Balancing: Distributing Traffic

- **Round Robin**: Distribute requests equally across servers
- **Least Connections**: Route to server with fewest active connections
- **IP Hash**: Consistent routing based on client IP for session affinity
- **Weighted**: Assign more traffic to powerful servers
- **Layer 4 vs Layer 7**: Network layer (TCP/UDP) vs Application layer (HTTP)
- Tools: Nginx, HAProxy, AWS ELB, Cloud Load Balancers




(Ref: https://www.geeksforgeeks.org/computer-networks/load-balancing-approach-in-distributed-system/)

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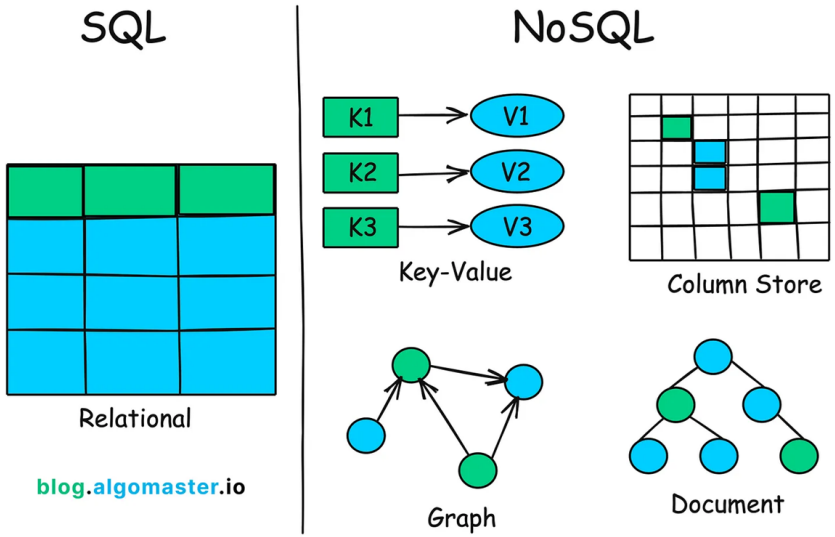
# Database Design: Choosing the Right Store

- **SQL (RDBMS)**: ACID, complex queries, relationships - MySQL
- **NoSQL Key-Value**: High performance, simple lookups - Redis
- **NoSQL Document**: Flexible schema, JSON - MongoDB, Couchbase
- **NoSQL Column-Family**: Time-series, analytics - Cassandra, HBase
- **NoSQL Graph**: Relationships, social networks - Neo4j
- Choose based on: consistency needs, query patterns, scale requirements




(Ref: https://www.geeksforgeeks.org/computer-networks/load-balancing-approach-in-distributed-system/)

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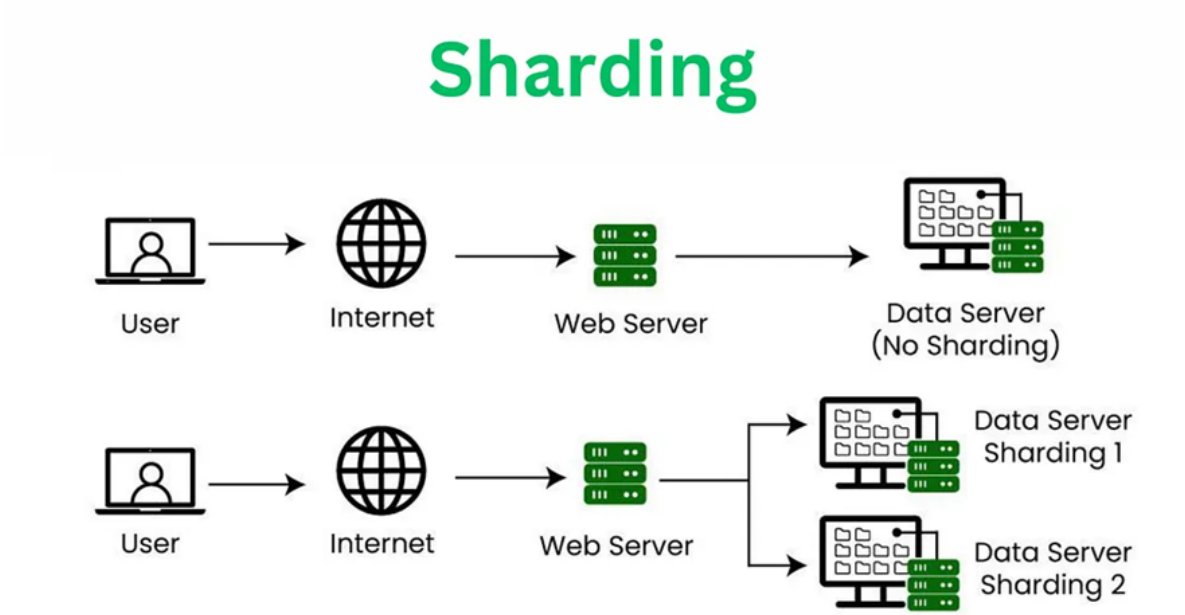
# Database Scalability: Handling Growth

- **Replication**: Master-slave for read scaling, Multi-master for write scaling
- **Sharding/Partitioning**: Horizontal split by key range, hash, or geography
- **Indexing**: B-trees for fast lookups, trade-off with write speed
- **Denormalization**: Duplicate data to avoid expensive joins
- **Connection Pooling**: Reuse database connections to reduce overhead
- CAP Theorem: Choose 2 of Consistency, Availability, Partition Tolerance




(Ref: https://medium.com/@hksrise/understanding-sharding-in-system-design-a-key-to-scalability-214ad71784c4)

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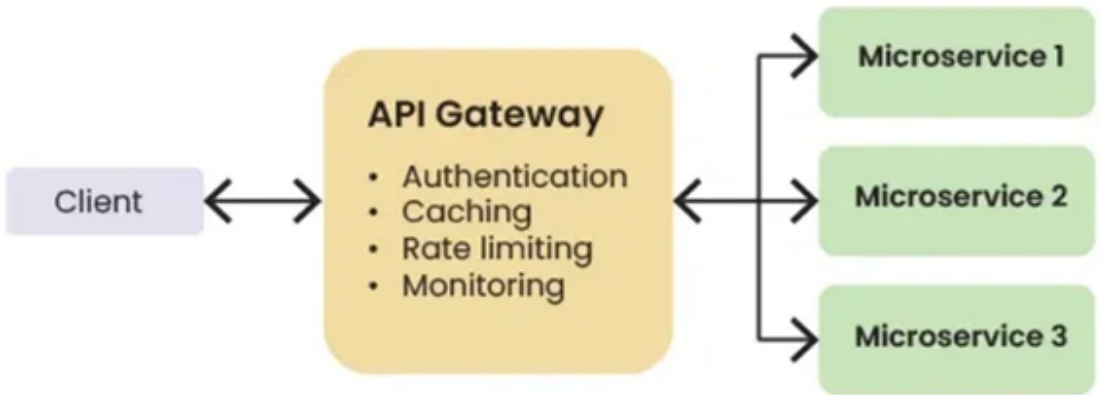
# API Design: Building Interfaces

- **REST**: Resource-based, HTTP methods (GET, POST, PUT, DELETE), stateless
- **GraphQL**: Flexible queries, single endpoint, client defines response structure
- **gRPC**: High performance, Protocol Buffers, bidirectional streaming
- **Versioning**: URL path (/v1/), header, or query parameter
- **Pagination**: Limit/offset or cursor-based for large datasets
- **Error Handling**: Consistent HTTP status codes and error messages




(Ref: https://www.geeksforgeeks.org/system-design/what-is-api-gateway-system-design/)

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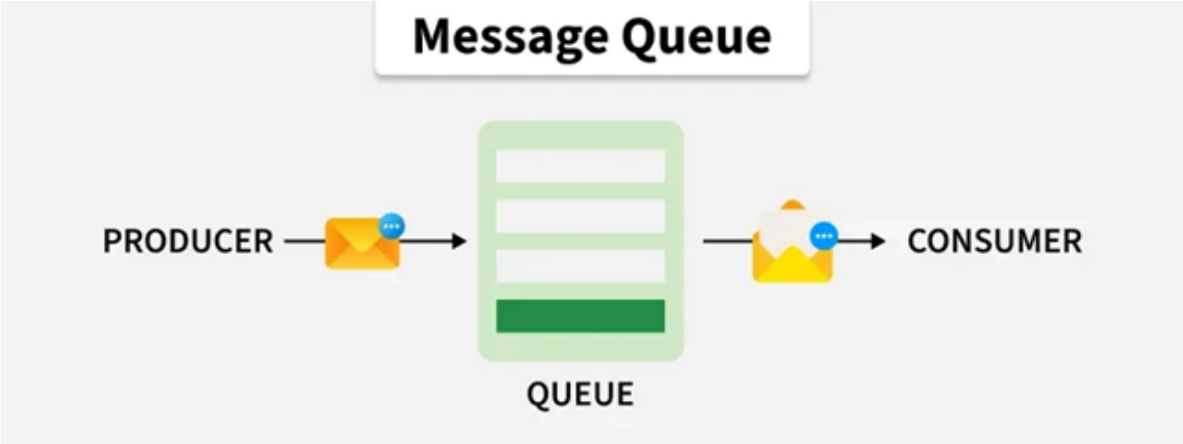
# Message Queues: Asynchronous Processing

- **Purpose**: Decouple services, handle traffic spikes, reliable delivery
- **Patterns**: Point-to-point (Queue), Publish-Subscribe (Topic)
- **Guarantees**: At-least-once, at-most-once, exactly-once delivery
- **Use Cases**: Order processing, email notifications, video encoding
- **Tools**: Kafka (high throughput), RabbitMQ (flexible), AWS SQS/SNS
- Consider: message ordering, idempotency, dead letter queues




(Ref: https://www.geeksforgeeks.org/system-design/message-queues-system-design/)

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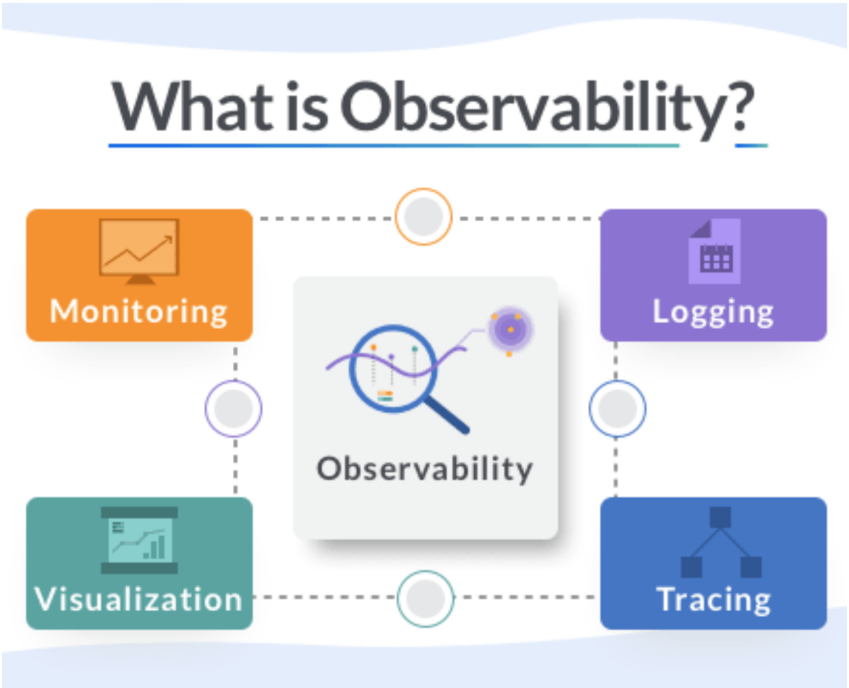
# Monitoring: Know Your System Health

- **Metrics**: CPU, memory, disk, request rate, latency (p50, p99), error rate
- **Logging**: Structured logs, centralized aggregation, log levels
- **Tracing**: Distributed tracing for microservices (Jaeger, Zipkin)
- **Alerting**: Threshold-based, anomaly detection, on-call rotation
- **Dashboards**: Real-time visualization (Grafana, Datadog)
- SLIs, SLOs, SLAs: Define reliability targets




(Ref: https://distributedcomputing.dev/SystemDesign/ObservabilityEngineering)

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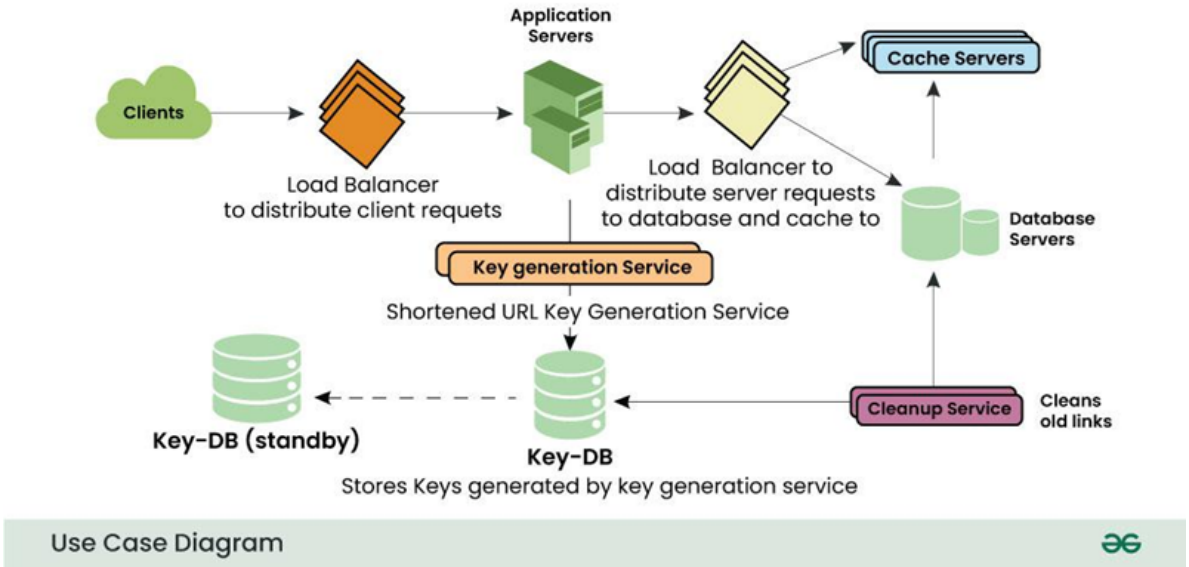
# Project: URL Shortener Design

- **Requirements**: Shorten URLs, redirect, analytics, 100M URLs, low latency
- **Hashing**: Base62 encoding (a-zA-Z0-9) of counter or MD5/SHA hash
- **Database**: Key-value store (shortURL → longURL), with index on shortURL
- **Caching**: Redis for hot URLs (80/20 rule), cache-aside pattern
- **API**: POST /shorten {longURL}, GET /:shortURL (302 redirect)
- **Scale**: DB sharding by hash, read replicas, CDN for static assets




(Ref: https://www.geeksforgeeks.org/system-design/system-design-url-shortening-service/)

# System Design: Structured Approach

- **Step 1**: Clarify requirements (functional, non-functional, scale)
- **Step 2**: Capacity estimation (storage, bandwidth, QPS)
- **Step 3**: High-level design (draw boxes and arrows)
- **Step 4**: Deep dive into components (database choice, caching)
- **Step 5**: Identify bottlenecks and optimize
- **Step 6**: Discuss trade-offs (consistency vs availability)
- Think aloud, communicate clearly, consider multiple solutions

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# Design Patterns: Quick Reference

- **Circuit Breaker**: Stop calling failing service, prevent cascading failures
- **CQRS**: Separate read and write models for different optimization
- **Event Sourcing**: Store state changes as events, rebuild state by replay
- **Saga Pattern**: Manage distributed transactions across microservices
- **Bulkhead**: Isolate resources to prevent total system failure
- **Strangler Fig**: Gradually replace legacy system

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# Conclusion: Mastering System Design

- Practice with real systems: Twitter, Netflix, Uber designs
- Understand trade-offs, not just solutions
- Keep learning: new technologies, patterns emerge constantly
- Resources: "Designing Data-Intensive Applications", System Design Primer (GitHub)
- Mock interviews: Practice communication and thinking process
- Remember: No perfect design, only appropriate design for requirements

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# References

Many publicly available resources are referred for this presentation.
Some of the notable ones are:

- An introduction to Python programming with NumPy, SciPy and Matplotlib/Pylab - Antoine Lefebvre
- Automate the Boring Stuff with Python - Al Sweigart (https://automatetheboringstuff.com/)
- Python Evangelism 101 - Peter Wang (https://conference.scipy.org/scipy2010/slides/lightning/peter_wang_python_evangelism.pdf)

Suggested Learning Resources:

- Book: van Rossum, G. (2011). The Python Tutorial (http://openbookproject.net/)
- PythonTurtle: Logo-like environment for kids and beginners. (http://pythonturtle.org/)
- Book: Learning Python by Mark Lutz & David Ascher. O'Reilly and Associates
- Python Cookbook http://aspn.activestate.com/ASPN/Cookbook/Python

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# Thanks . . .

- Office Hours: Saturdays, 3 to 5 pm (IST); Free-Open to all; email for appointment to yogeshkulkarni at yahoo dot com
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(https://www.github.com/yogeshhk/ )

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# Pune AI Community (PAIC)

- Two-way communication:
  - Website puneaicommunity dot org
  - Email puneaicommunity at gmail dot com
  - Call + 9 1 9 8 9 0 2 5 1 4 0 6
  - LinkedIn: https://linkedin.com/company/pune-ai-community
- One-way Announcements:
  - Twitter (X) @puneaicommunity
  - Instagram @puneaicommunity
  - WhatsApp Community: Invitation Link https://chat.whatsapp.com/LluOrhyEzuQLDr25ixZ
  - Luma Event Calendar: puneaicommunity
- Contribution Channels:
  - GitHub: Pune-AI-Community and puneaicommunity
  - Medium: pune-ai-community
  - YouTube: @puneaicommunity

Website

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# Pune AI Community (PAIC) QR codes

Website

LinkedIn Page

Luma Events

Medium Blogs

Github Repository

YouTube Videos

Twitter-X

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