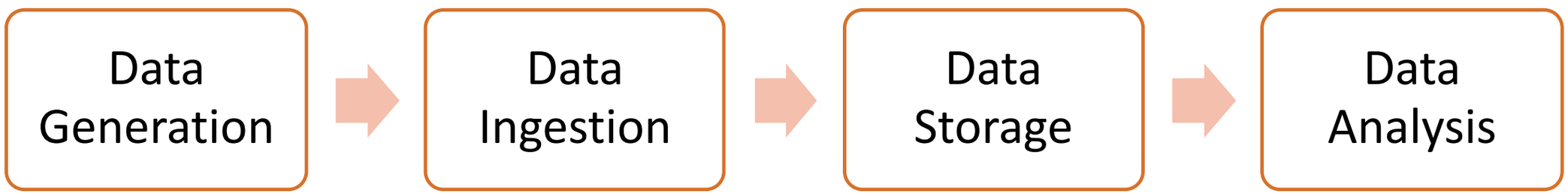
2110403 - Introduction to Data Science and Data Engineering

Data Storages

Asst.Prof. Natawut Nupairoj, Ph.D.
Department of Computer Engineering
Chulalongkorn University
natawut.n@chula.ac.th

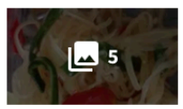
CHULA ENGINEERING
Foundation toward Innovation

Data Lifecycle



Traditional Database

- Based on ”relational model”
  - Data is split and stored into tables
  - Tables can be processed together using set-like operations
  - Data model is usually normalized to remove duplication
- Very suitable for OLTP or transaction systems
  - Provide lots of complicated SQL operations
  - Lots of inserts and updates



Prep Time:	Total Time:	Servings:
20 mins	20 mins	6

Jump to Nutrition Facts

Ingredients

- 3 cloves garlic, peeled
- 3 Thai green chiles
- 6 green beans, cut into 1-inch pieces
- 1 large unripe papaya, peeled and cut into

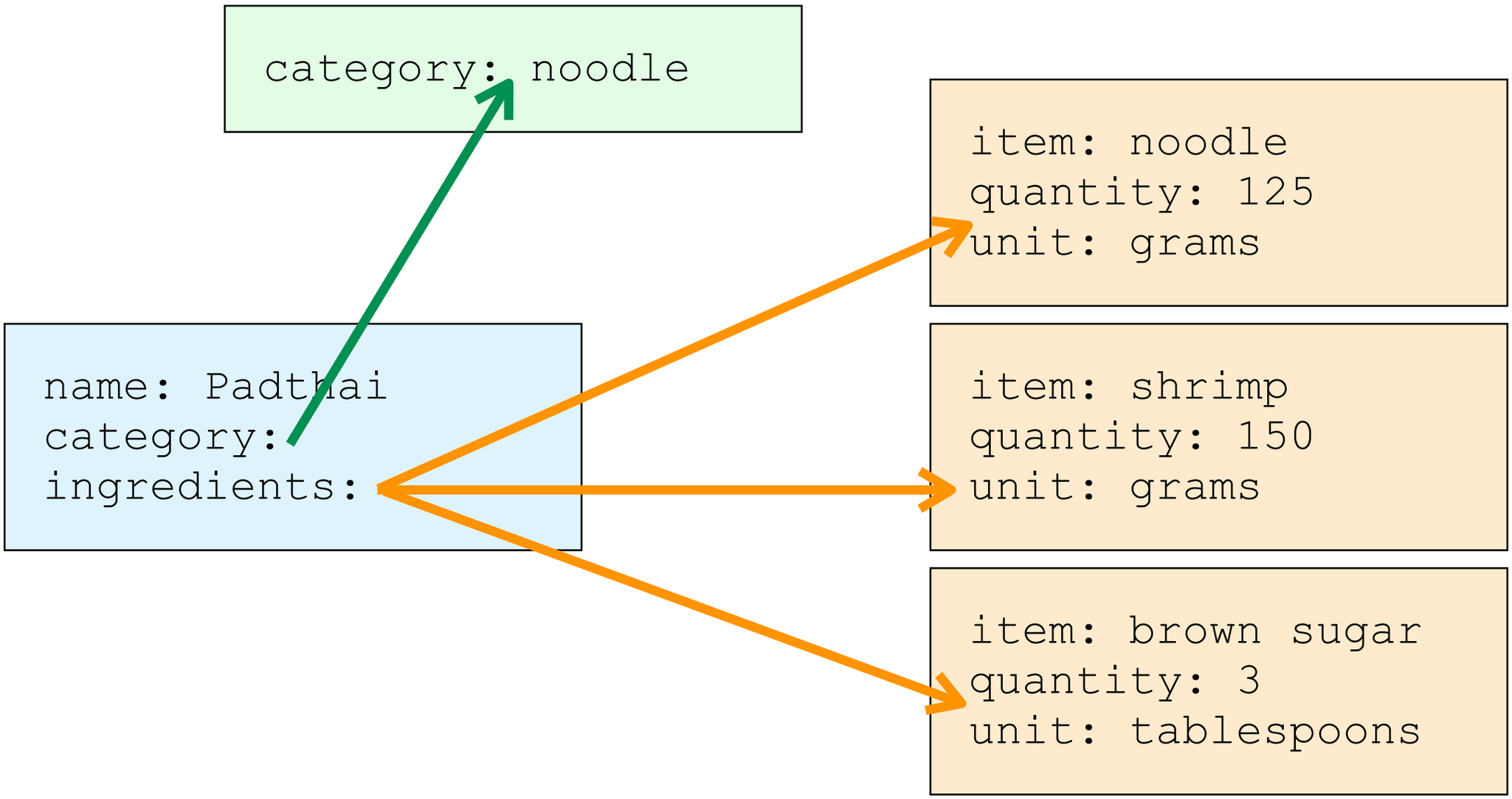
Local Offers

00000 Change

Oops! We cannot find any ingredients on sale near you. Do we have the correct zip code?

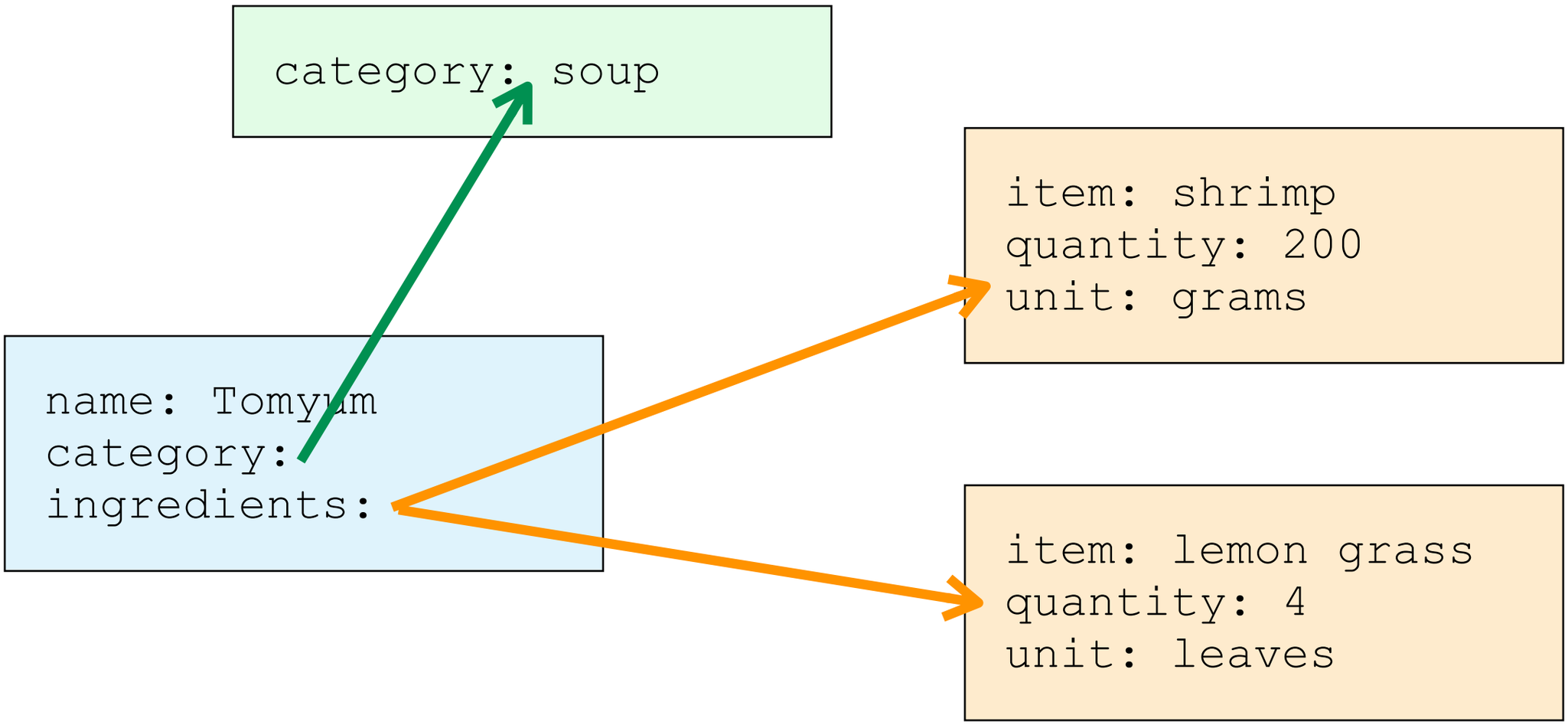
Recipe Data Example

- Padthai belongs to a noodle category with 3 main ingredients noodle, shrimp, brown sugar



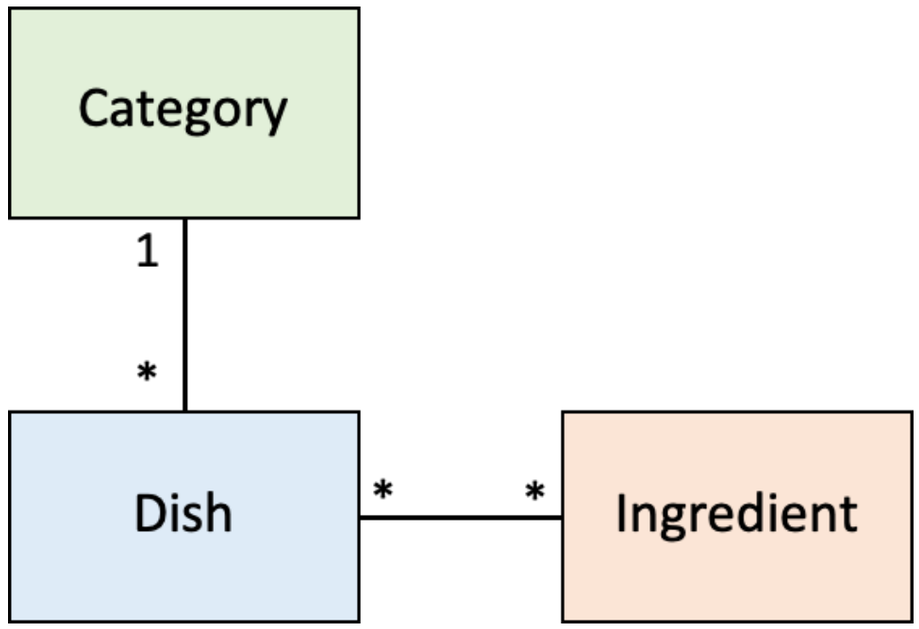
Recipe Data Example

- Tomyum belongs to a soup category; shrimp and lemon grass are main ingredients



Recipe Data is Hierarchical

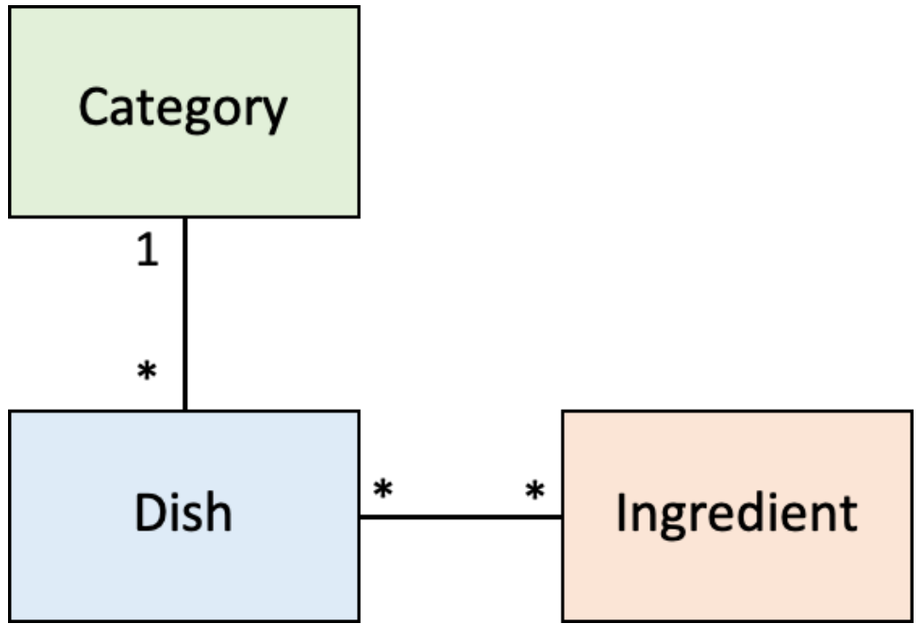
- A dish has the following data:
  - belong to a category
  - consists of one or more main ingredients
  - Ingredients are different in portions and units



Example RDBMS: Recipe

Category

id	category
1	Soup
2	Noodle
3	Rice



Dish

id	name	category	…
1203	Pad Thai	2	
1288	Chicken Rice	3	

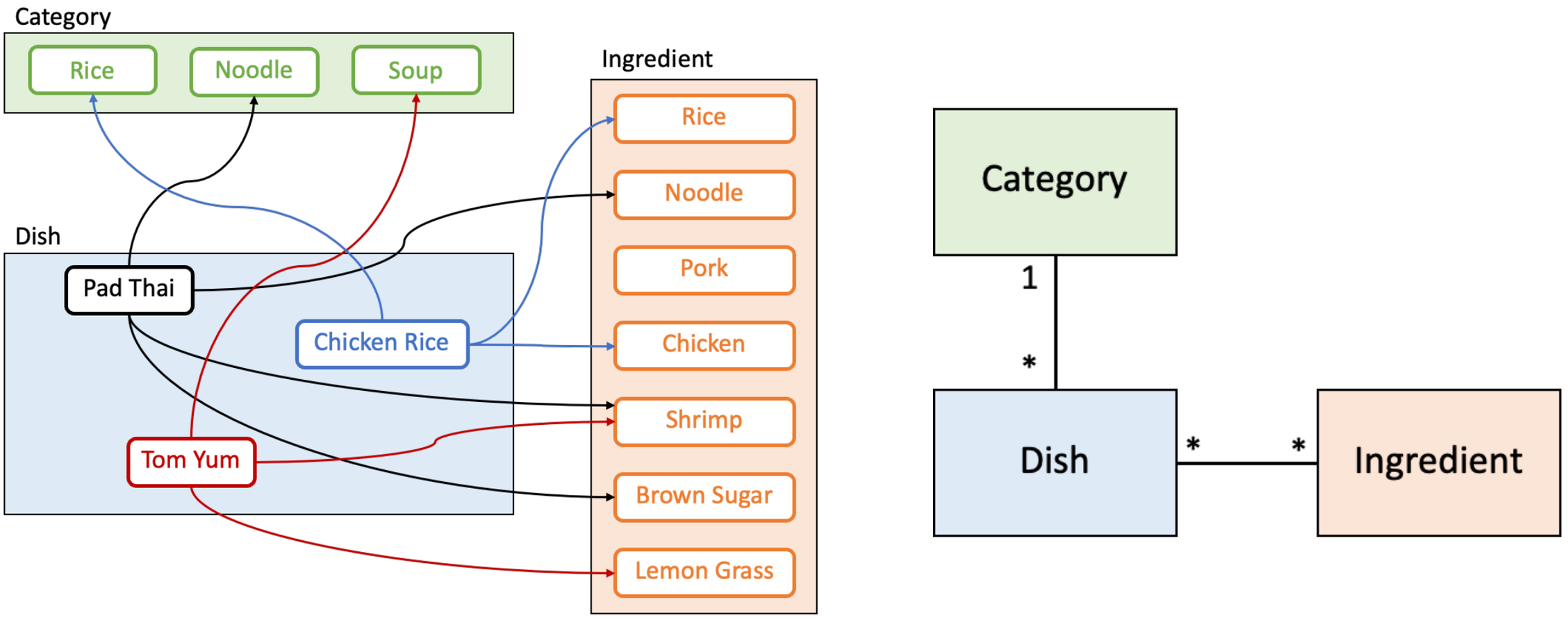
DI_link

d_id	i_id	quantity	unit
1203	45	125	g
1203	48	150	g
1203	52	3	tbsp

Ingredient

id	item
45	noodle
46	rice
48	shrimp
52	brown sugar

Relational Database: Normalized Data Model



How can we split these tables to lots of machines?

- Dishes of the same category in the same machine
- How about dishes and ingredients?

Or we can replicate data — lead to data consistency problems

Problems of Data Science Storage

- There are several needs for data analytics purposes e.g. traditional data store, caching, feature store
- Data is historical data and its volume can be huge
- Scalability is extremely important and “Relational + Consistency” can limit scalability
- SQL command can be very complex and time-consuming
  - It requires the synchronization of data accessing between multiple tables
  - It will be poor when using on more than a few servers in the same cluster

CAP Theorem (Brewer's Theorem)

- By Eric Brewer (University of California, Berkeley)
- It is impossible for a distributed computer system to simultaneously provide all three of the following guarantees: Consistency, Availability, Partition tolerance
- When the communication failure occurs, the system has to choose either consistency or availability

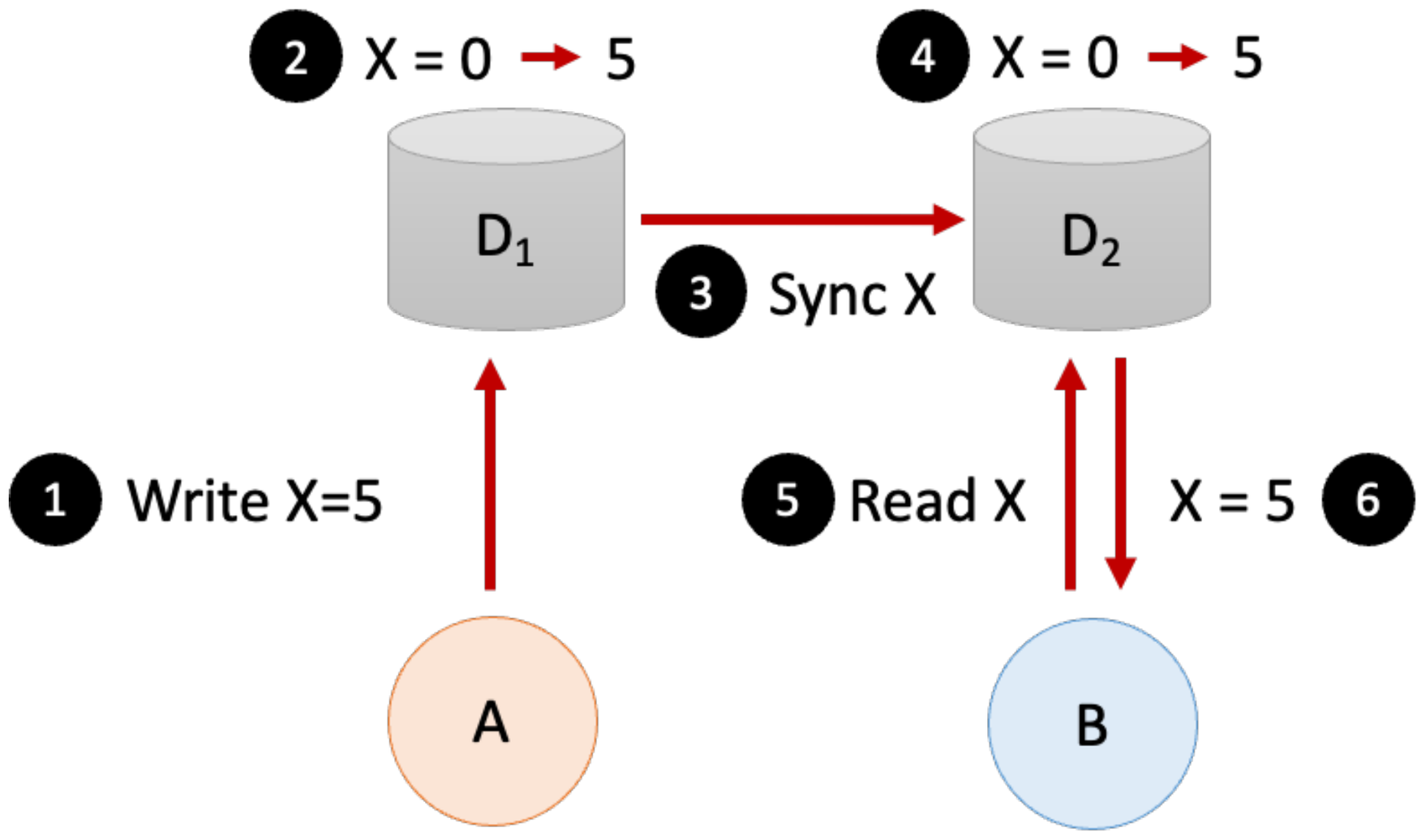
CAP Theorem Scenario

- Distributed system (clients and servers)
- Multiple servers working together
- Multiple clients may read or write on the same data at the same time

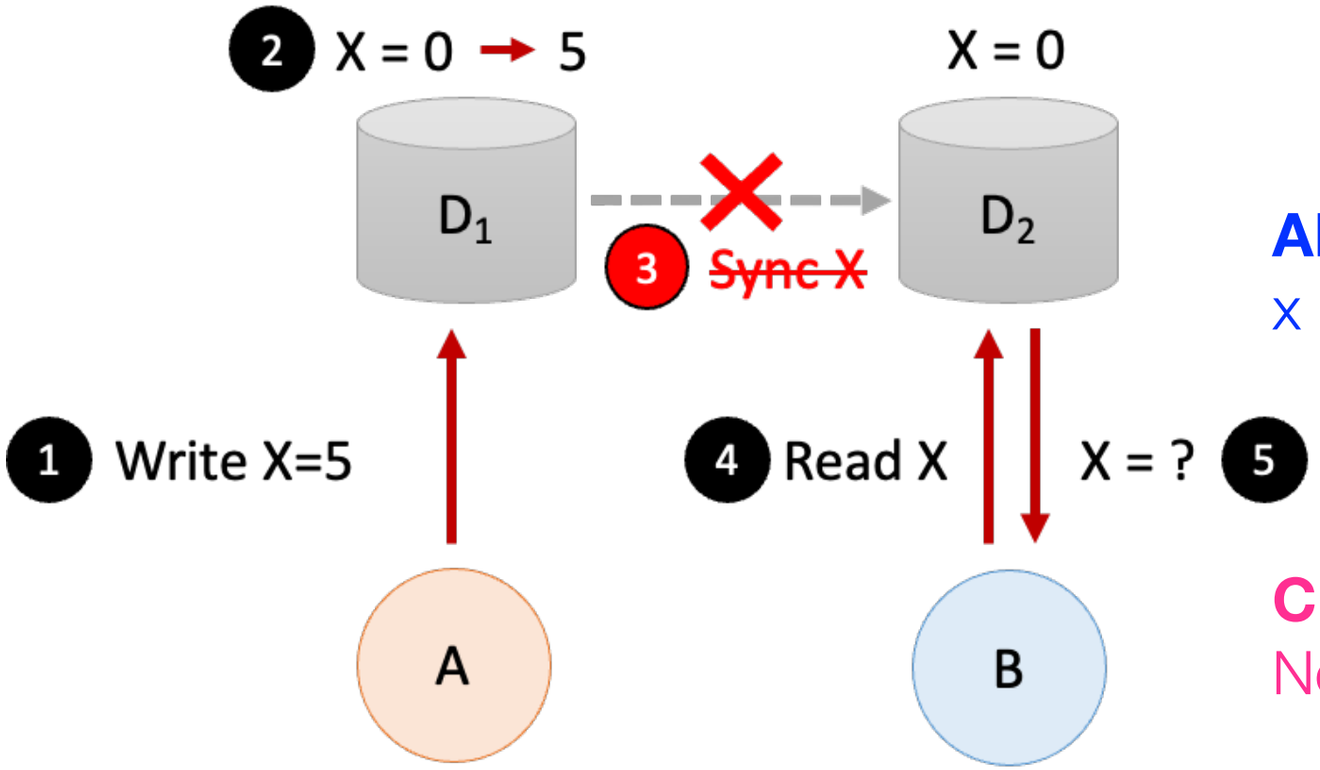
CAP Guarantees only 2 out of 3

- Consistency
  - Every read receives the most recent write or an error
- Availability
  - Every request receives a (non-error) response – without guarantee that it contains the most recent write
  - Response from any server is good
- Partition tolerance
  - The system continues to operate despite arbitrary message loss or failure of part of the system
  - Lots of servers require long synchronization time causing servers to not be able to communicate among one another within reasonable time

CA Data Store



Given P, Choosing between C and A (at step 5)



AP Data Store

x = 0 (not consistent, but available)

CP Data Store

No response

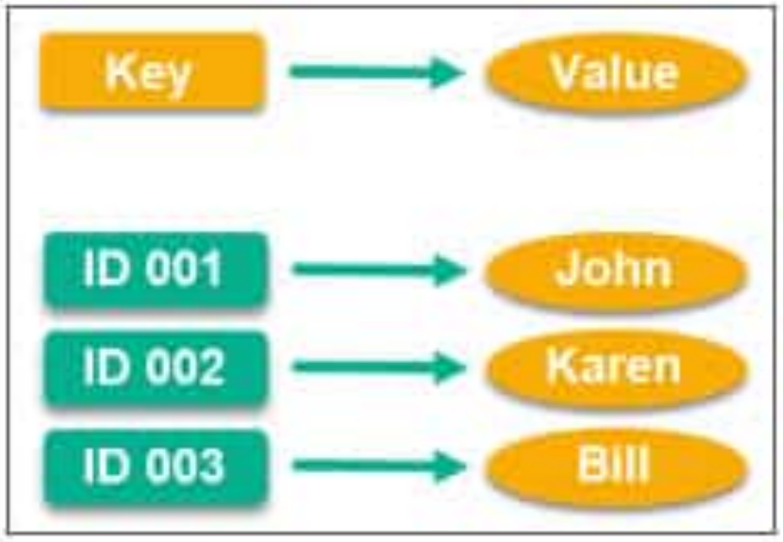
More Scenario - when partition occurs

- CA - cannot operate
- CP
  - allow read requests and reject all write requests
  - allow read and write at a group that still connects to a master node

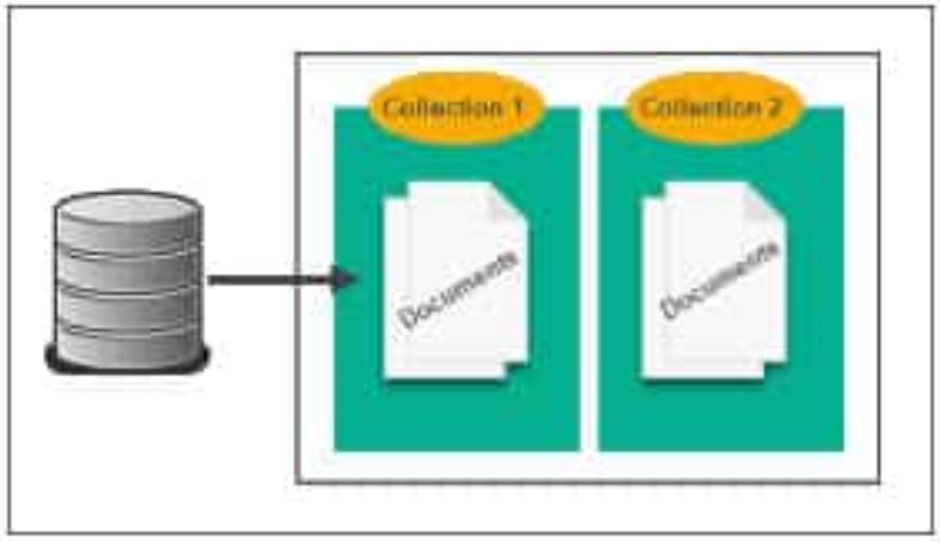
The Landscape of NoSQL

- Alternatives to SQL database
  - non-relational
  - distributed
  - horizontally scalable
- Data is shared and distributed across multiple servers
- Typically use weak consistency model (but not always)

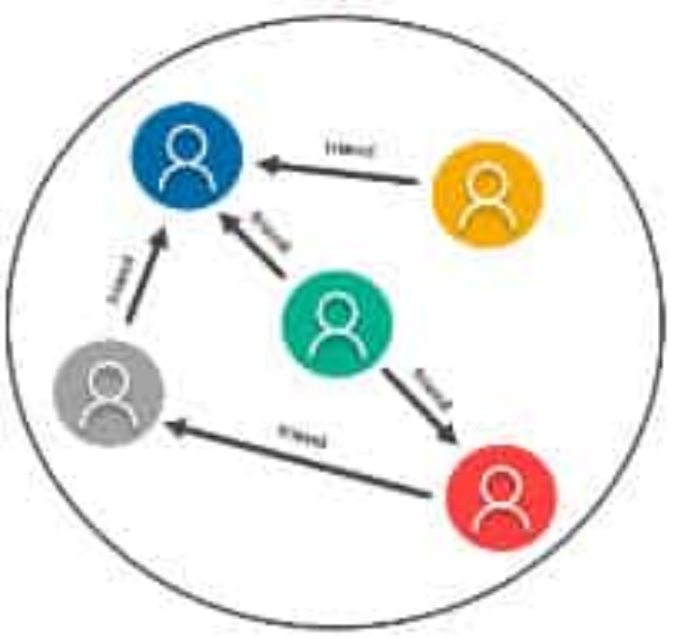
Key-value



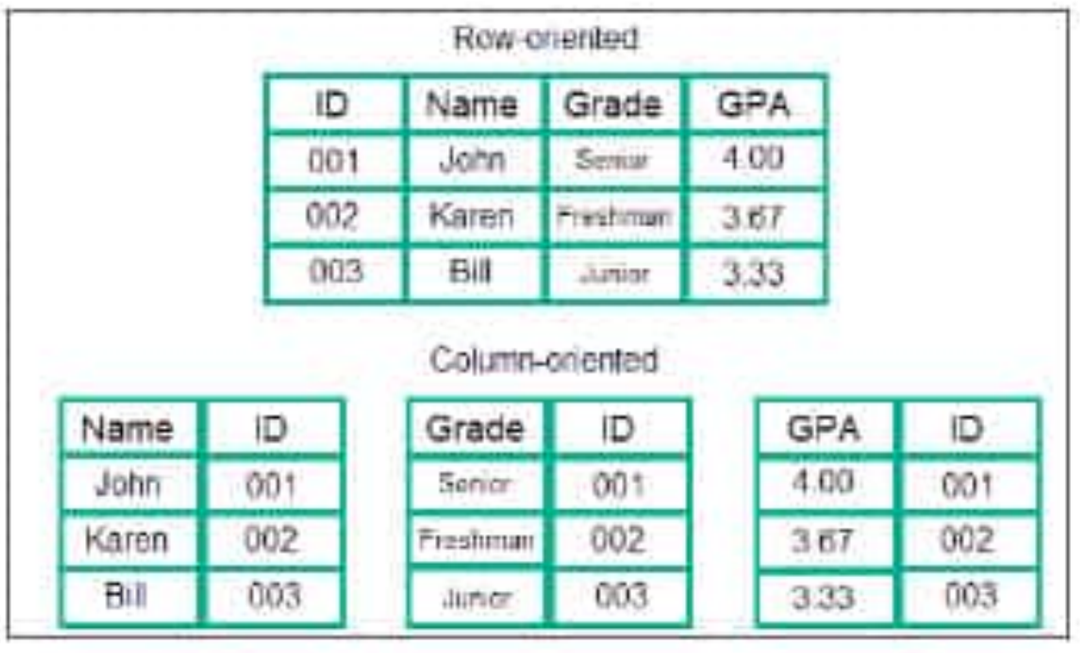
Document



Graph



Wide-column



Source: https://www.linkedin.com/pulse/sql-nosql-databases-mustafa-qizilbash/

Types of NoSQL

- Document: MongoDB, DynamoDB, CosmosDB, Couchbase, Firebase
- Column: Cassandra, HBase, CosmosDB, Accumulo
- Key-value: Redis, DynamoDB, CosmosDB, MemcacheDB
- Graph: Neo4J, TigerGraph, ArrangoDB, OrientDB
- Search Engine: Elasticsearch, Splunk, Solr
- Timeseries: InfluxDB, TimescaleDB, Prometheus, Graphite
- Vector: Chroma, Pinecone,

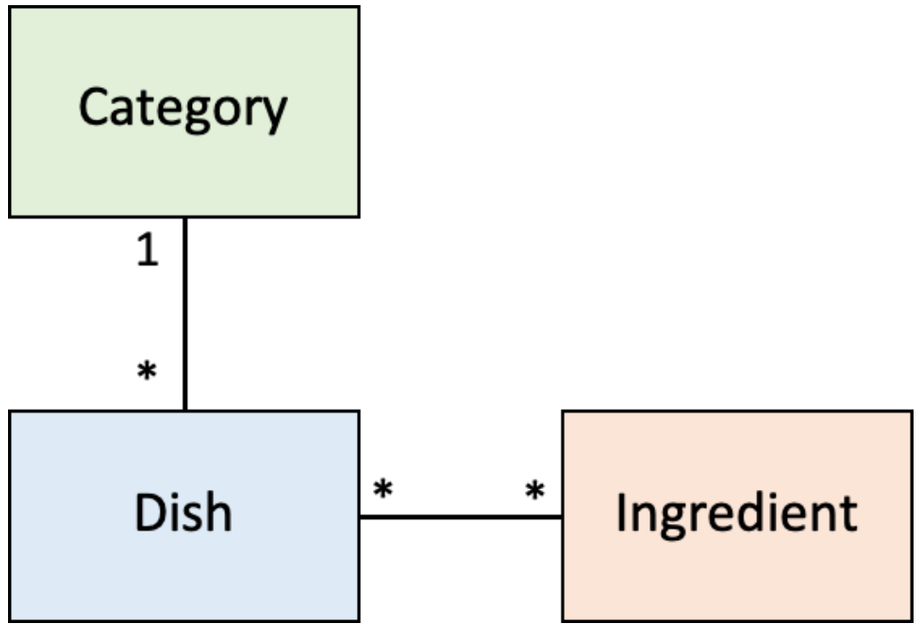
How NoSQL can “Scale”

- Principle ideas
  - Split data into chunks or shards
  - Distribute data across multiple servers
  - Must require minimum synchronization
- Have to give up some traditional features
  - No complex relational model
  - Relax consistency
  - Duplicated information (not space optimized)
  - Fast to insert new record, but not so fast to update the existing one

Example RDBMS: Recipe

Category

id	category
1	Soup
2	Noodle
3	Rice



Dish

id	name	category	…
1203	Pad Thai	2	
1288	Chicken Rice	3	

DI_link

d_id	i_id	quantity	unit
1203	45	125	g
1203	48	150	g
1203	52	3	tbsp

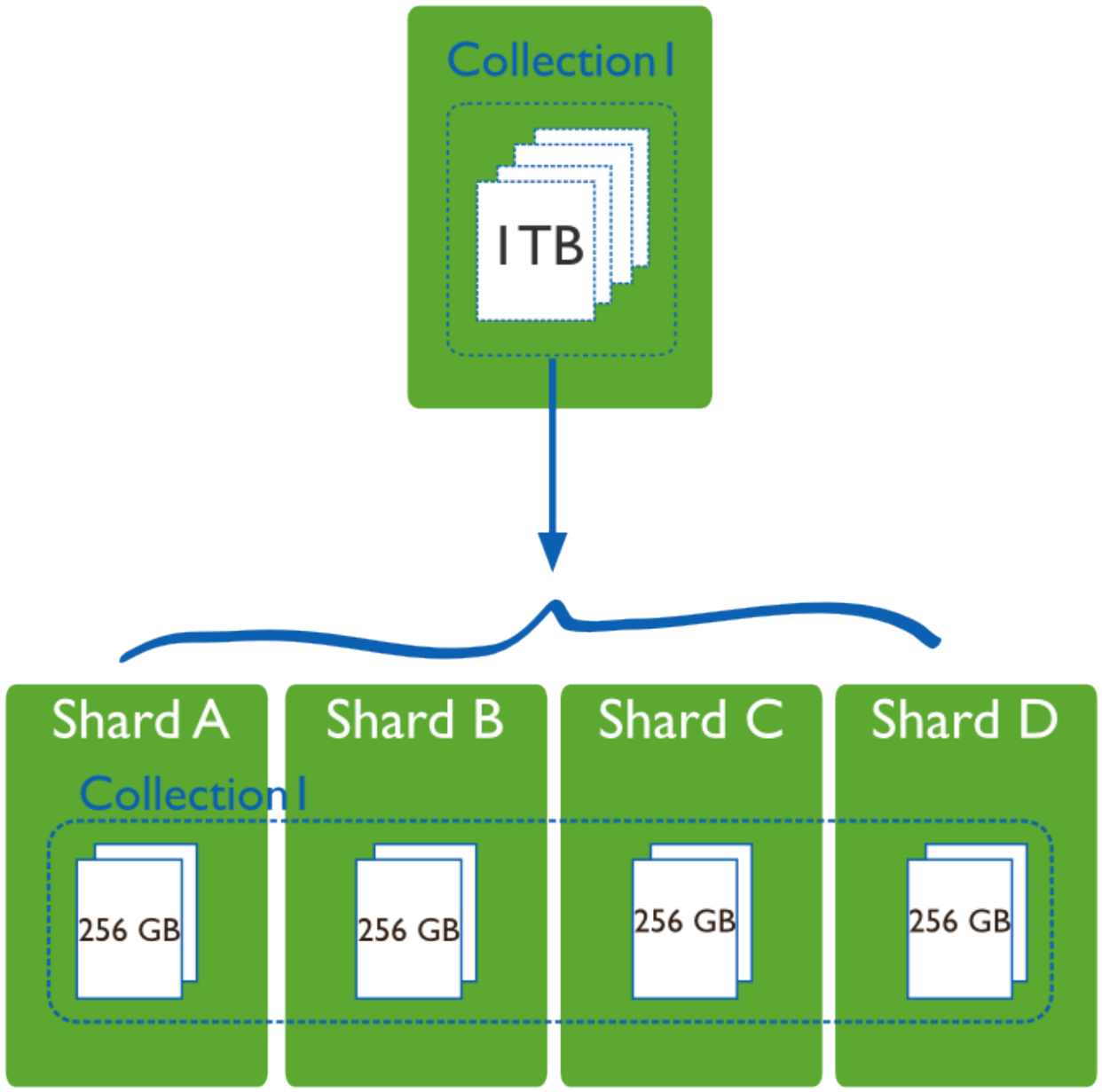
Ingredient

id	item
45	noodle
46	rice
48	shrimp
52	brown sugar

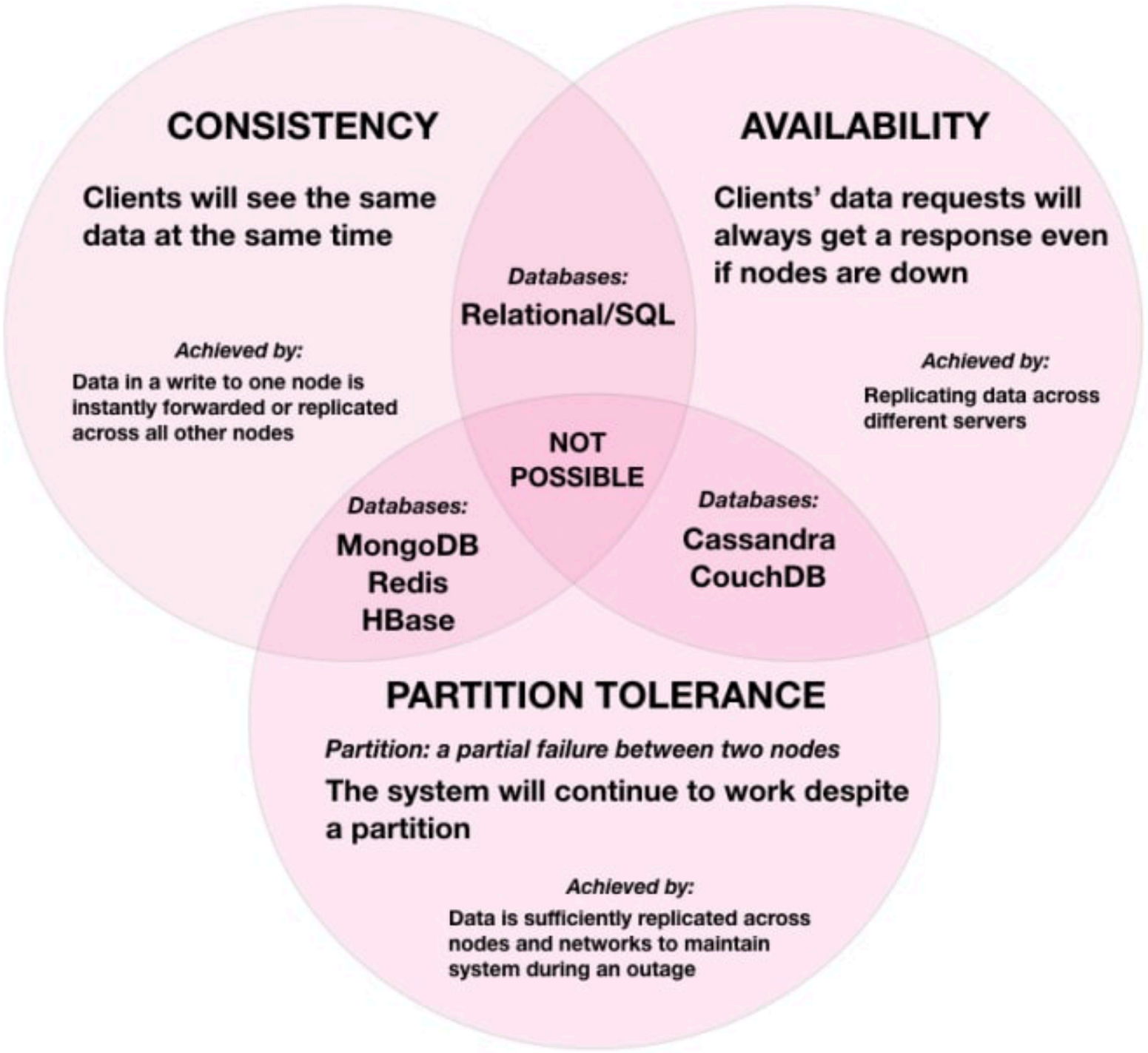
Example MongoDB: Recipe

```
{
   _id: ObjectId ("507f191e810c19729de860ea""),
   name: "Pad Thai",
   cuisine: "Thai",
   category: "Noodle",
   rating: 4.7,
   votes: 9301,
   ingredients: [
      { item: "noodle", quantity: "125", unit: "g" },
      { item: "shrimp", quantity: "150", unit: "g" },
      { item: "brown sugar", quantity: "3", unit: “tbsp" }
   ]
}
```

How MongoDB Scales - Sharing



- Large-Scale MongoDB bases on Horizontal Scaling mechanism
- Storing shards (blocks of data) across multiple machines
- Data partitioned into shards with shard keys
- Each shard handles only operations related to its block



Source: https://dev.to/katkelly/cap-theorem-why-you-can-t-have-it-all-ga1

Redis
Key-Value Store

Data Storage

Key-Value Stores

- A data store designed for storing, retrieving, and managing associative arrays (aka. dictionary or hash table)

- Main concept is to store data as a collection of key-value pairs in which a key serves as a unique identifier

- Simple and fast, often use in-memory architecture, ability to scale-out

- Use cases: Database/API caching, session store, shopping cart, etc.

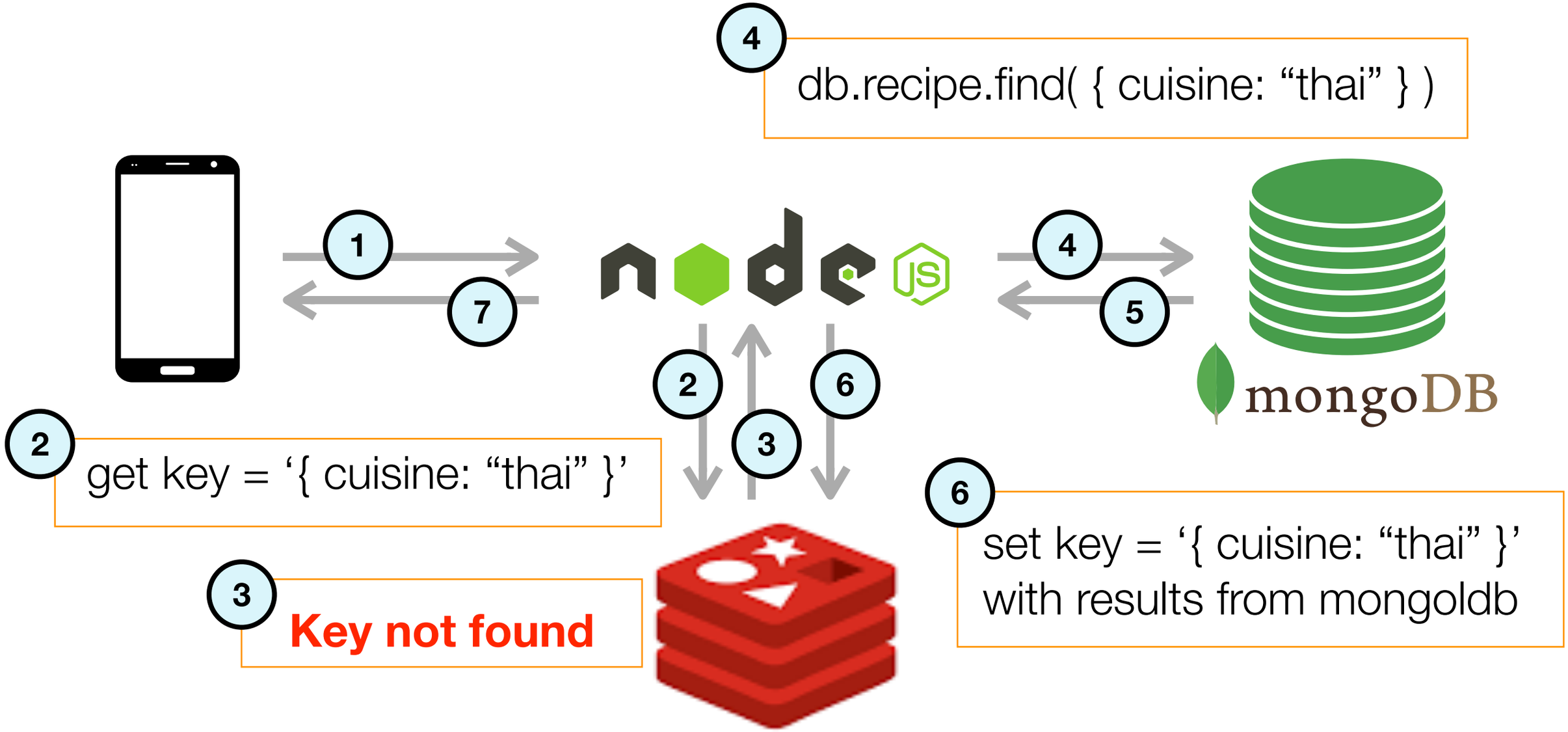
Redis (Remote Dictionary Server)

- In-memory data structure store with clustering, transactional, time-to-live limiting, and auto-failover capabilities
- Support wide-range of data structure with lots of related operations for each structure
- Being used for database cache, message broker, streaming engine, feature store engine, etc.
- Provide CLI and support many programming languages
- Many useful modules are available to extend the functionality of Redis core e.g. RedisJSON, RedisSearch, RedisTimeSeries, Redis OM, etc.

Typical Web Application Architecture

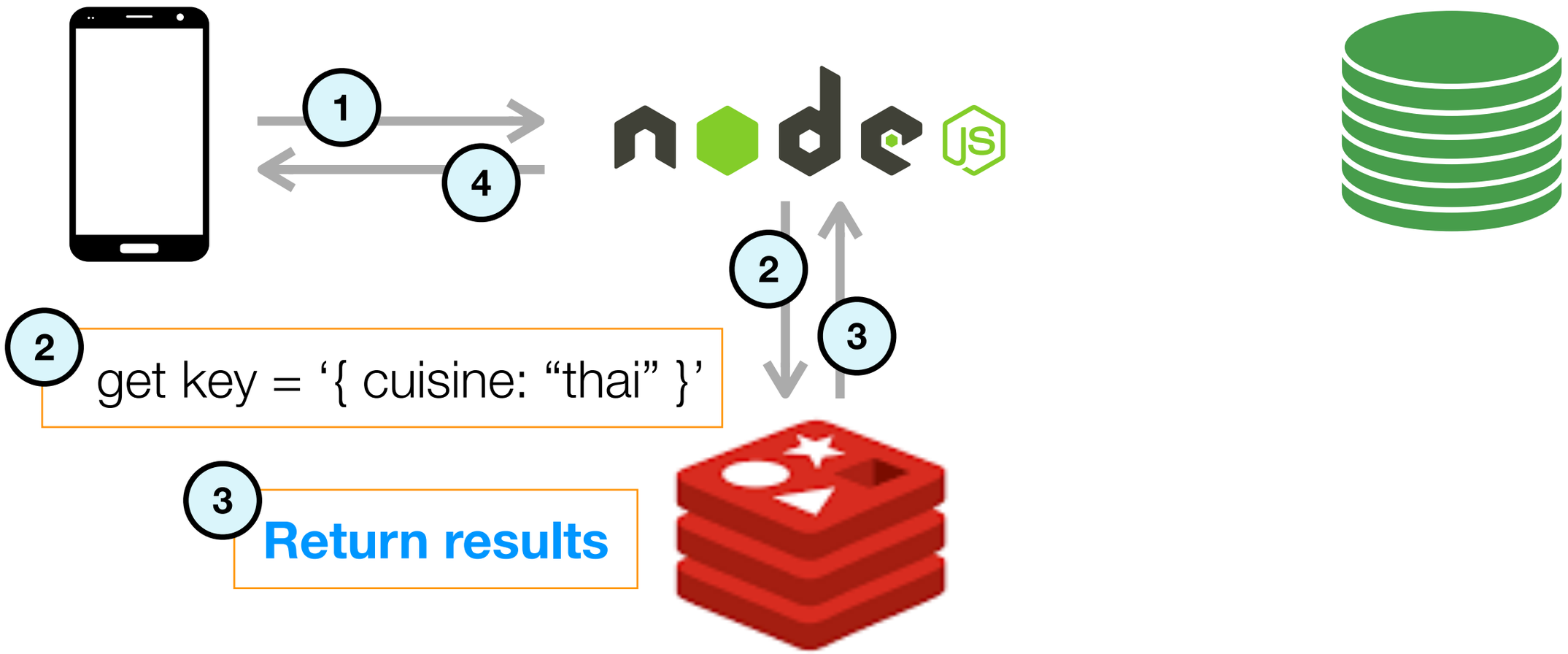
Database latency = 100ms per query
Effective latency = 100ms per query

Redis as Database Cache
First Time = Cache Miss



Redis latency = 5ms per operation
Database latency = 100ms per query
Effective latency = 110ms per query

Redis as Database Cache
First Time = Cache Hit



Redis latency = 5ms per operation
Effective latency = 5ms per query

Benefits of Using Cache

- Each request results to either cache hit (5ms) or cache miss (100ms)
- Cache hits come from using the same request, suppose this happens 80% of the time (cache hit rate)
- If cache is not hit, it is a cache miss, thus:
  cache miss rate = 1 - cache hit rate

```
Effective Latency =
        Cache Hit Rate * Cache Hit Latency +
        Cache Miss Rate * Cache Miss Latency
      = 0.8 * 5 + (1 - 0.8) * 100
      = 4 + 20
      = 24 ms
```

Running Redis

- The simplest way to run a redis instance is to use docker

```
docker pull redis
docker run -d --rm --name redis -p 6379:6379 redis
```

- This will start redis in your docker at port 6379 and map the port to your localhost

- You can also use docker-compose.yml and other example files in redis folder in datasci_architecture repo

Working with Redis

- Redis CLI
  - Standard client program to connect to any redis server
  - Come with any redis installation (see: https://redis.io/docs/getting-started/)

```
redis-cli

redis-cli -h 34.143.227.66
```

  - You can type in redis command in the CLI input

Working with Redis

- Redis-Py
  - Standard python package for redis client

```
pip install redis
```

- Example

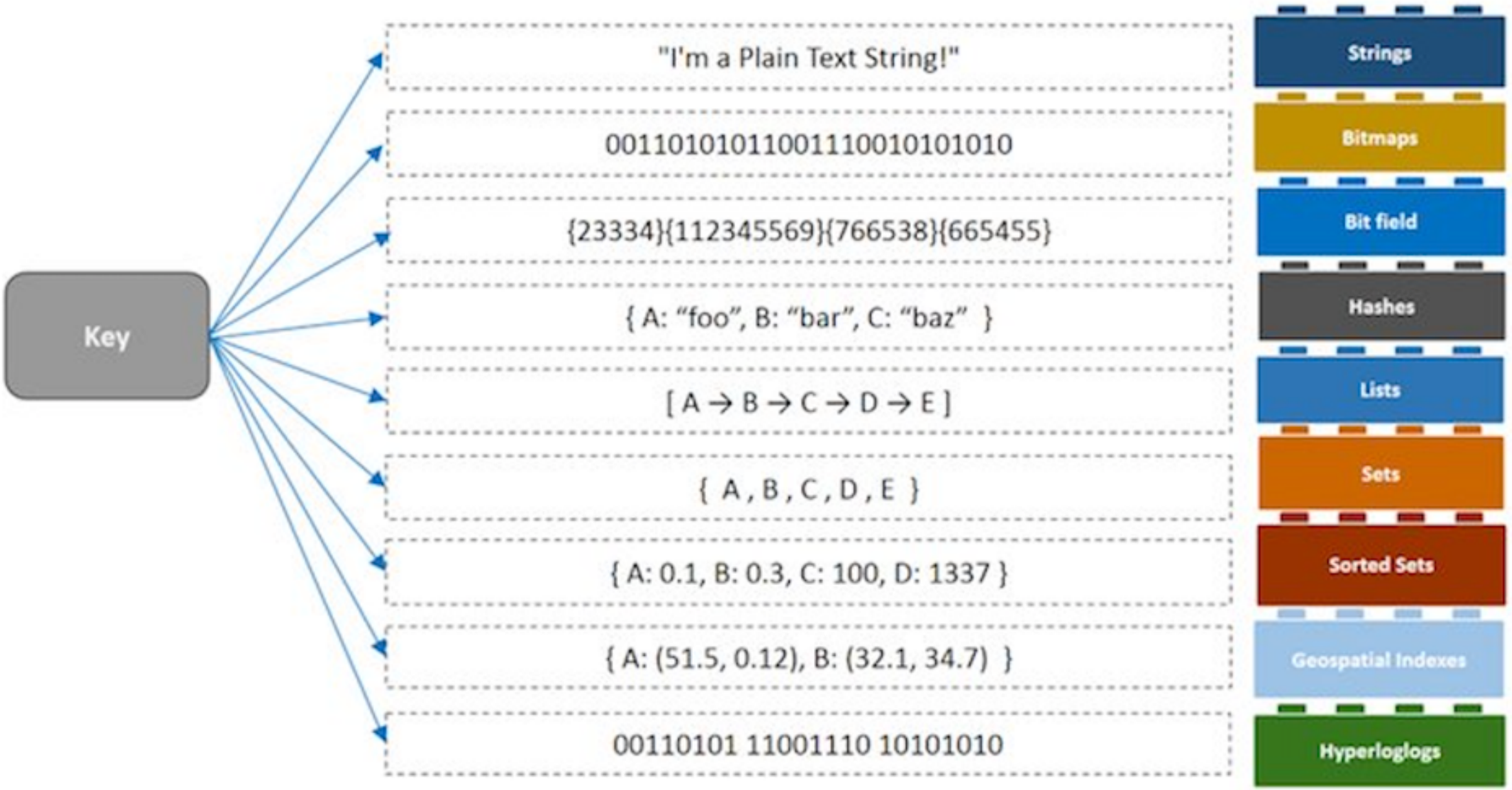
```
import redis

r = redis.Redis(host='hostname', port=port)
```

Redis Key

- Each record is “Key” and “Value”
- Redis keys are binary safe; any binary sequence as a key, from a string like "foo" to the content of a JPEG file
- Maximum key size is 512 MB
- Key should follow some consistent patterns e.g. “object-type:id” (e.g. “user:1234”)
- Key pattern design is very important, especially for data retrieval

Redis Value Data Types



String

- Similar to Python or Java Strings, maximum length of 512MB

```
SET “user” “Natawut Nupairoj”
GET “user”
DEL “user”
```

- Use cases
  - Server-side object cache e.g. HTML fragments
  - Database/API cache

JSON String

Key	Value
cache:cuisine:thai	“[{{name:’padthai’,cuisine:’thai’,…},,…]”

Other String Commands

APPEND

DECR

DECRBY

GET

GETDEL

GETEX

GETRANGE

GETSET

INCR

INCRBY

INCRBYFLOAT

LCS

MGET

MSET

MSETNX

PSETEX

SET

SETEX

SETNX

SETRANGE

STRLEN

SUBSTR

Useful Commands

- Any item in Redis can be made to expire after or at a certain time

```
EXPIRE user 60.  # in seconds
TTL user
```

- You can scan all index with scan command

```
SCAN 0
```

- You can delete item or test its existence

```
DEL mykey
EXISTS mykey
```

List

- List of strings, sorted by insertion order
- Can be used as list, queue, stack

```
LPUSH mylist abc  # mylist contains “abc”
LPUSH mylist xyz # mylist contains “xyz”, “abc”
RPUSH mylist 123 # mylist contains “xyz”, “abc”, “123”
```

- Use cases
  - Queue
  - Shopping carts
  - Timelines

Key	Value
task:queue	[“task:37492”, “task:40938”, “task:49274”, …]

List Commands

BLMOVE

BLMPOP

BLPOP

BRPOP

BRPOPLPUSH

LINDEX

LINSERT

LLEN

LMOVE

LMPOP

LPOP

LPOS

LPUSH

LPUSHX

LRANGE

LREM

LSET

LTRIM

RPOP

RPOPLPUSH

RPUSH

RPUSHNX

Set

- Powerful data types for unordered non-duplicated keys
- Support many set operations e.g. intersection, union, etc.

```
SADD user_set natawut
SCARD user_set
SMEMBERS user_set
```

- Use cases
  - Set of user profiles
  - Set of inappropriate words for inappropriate content filtering

Key	Value
words:denied	{ “YLIJIL”, “KJLYGKIJ”, “*&^%^*^”, … }

Set Commands

SADD

SCARD

SDIFF

SDIFFSTORE

SINTER

SINTERCARD

SINTERSTORE

SISMEMBER

SMEMBERS

SMISMEMBER

SMOVE

SPOP

SRANDMEMBER

SREM

SSCAN

SUNION

SUNIONSTORE

Sorted Set

- Set of sorted items based on the score associated to each member

```
ZADD my_sortedset 5 data1
ZADD my_sortedset 1 data2 10 data3
ZRANGEBYSCORE my_sortedset 5. +inf WITHSCORES
```

- Use
  - Leader scoreboard
  - Priority queue

Sorted Set Commands

BZMPOP

BZPOPMAX

BZPOPMIN

ZADD

ZCARD

ZCOUNT

ZDIFF

ZDIFFSTORE

ZINCRBY

ZINTER

ZINTERCARD

ZINTERSTORE

ZLEXCOUNT

ZMPOP

ZMSCORE

ZPOPMAX

ZPOPMIN

ZRANDMEMBER

ZRANGE

ZRANGEBYLEX

ZRANGEBYSCORE

Hash

- A container of unique fields and their values

```
HMSET profile:12345 user nnp id 12345  name “Natawut Nupairoj” balance 10
HGETALL profile:12345
HINCRBY profile:12345 balance 5
```

- Use
  - User profile information
  - Post. Information

Key	Value
profile:12345	{ user: “nap”, id: “12345”, name: “Natawut… }

Hash Commands

HDEL

HEXISTS

HGET

HGETALL

HINCRBY

HINCRBYFLOAT

HKEYS

HLEN

HMGET

HMSET

HRANDFIELD

HSCAN

HSET

HSETNX

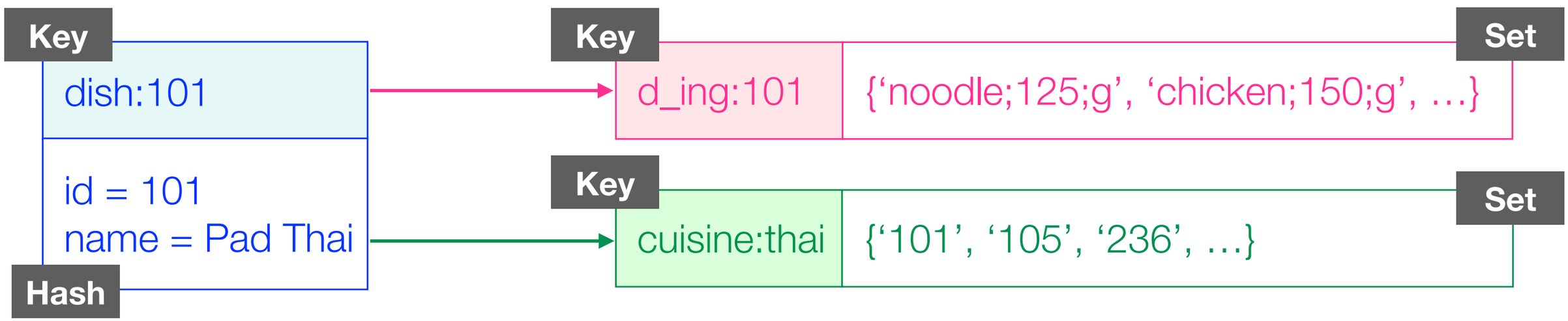
HSTRLEN

HVALS

Example: Recipes in Redis

- Create data model for recipe
- Data items
  - Main data
    - Dish - hash - key = dish:dish_id, value = dish_id, name, category, cuisine
    - Dish Ingredients - set - key = d_ing:dish_id, value = string(name; size; unit)
  - For query
    - Cuisine - set - key = cuisine:cuisine_value, value = string(dish_id)
- Relationship
  - 1 dish can have multiple ingredients
  - Cuisine, as a helper data item, points back to dishes belong in the cuisine
- This is only one example of model design

Example: Recipes in Redis



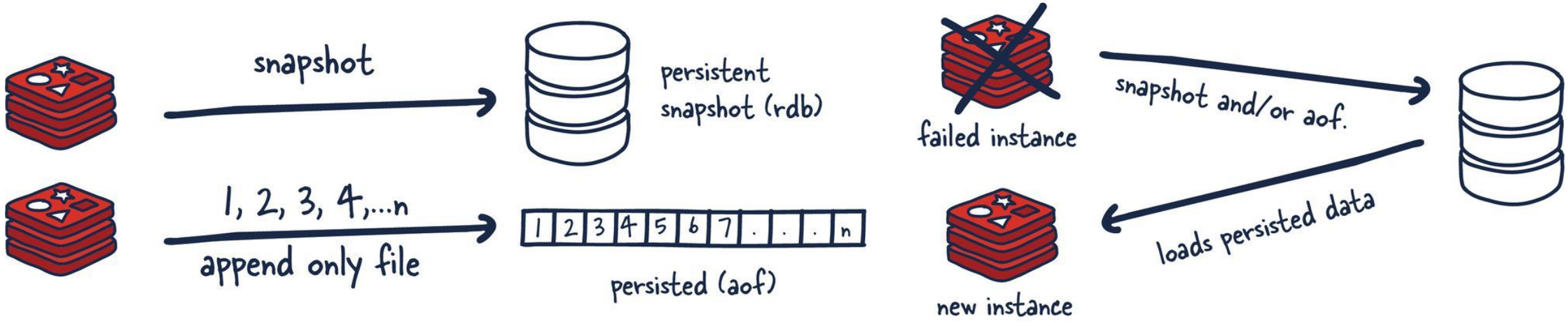

```
HMSET dish:1 id 101 name “Pad Thai” cuisine “thai” category “noodle”

SADD d_ing:101 “noodle;125;g”
SADD d_ing:101 “shrimp;150;g”
SADD d_ing:101 “brown sugar;3;tbsp”

SADD cuisine:thai “101”
```

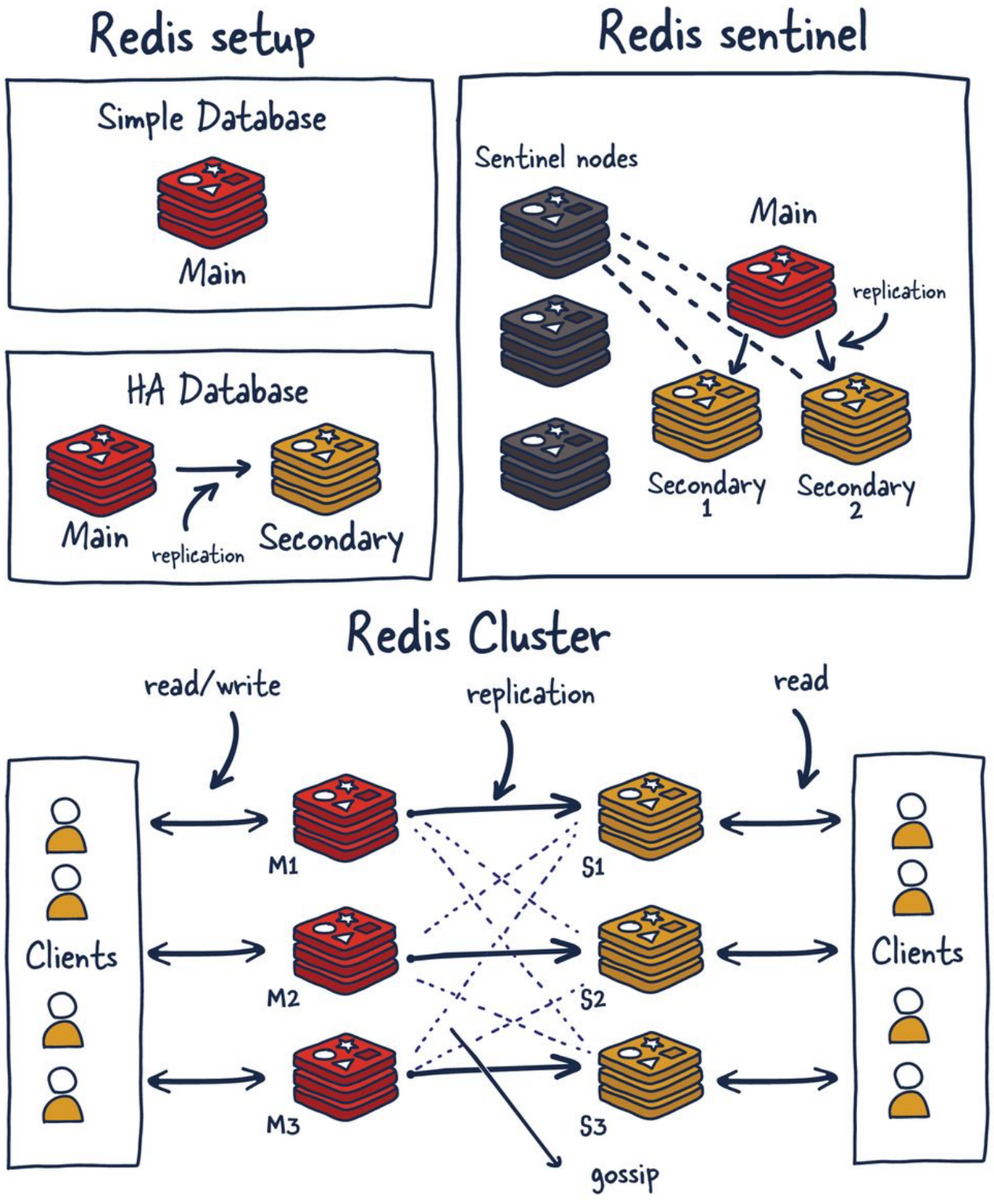
Redis Persistence

- Redis supports many level of persistence: no persistence, RDB (point-in-time snapshot), AOF (log every write), RDB+AOF



Redis Architecture

- Redis supports flexible architecture
  - Single instance
  - High Availability
  - Sentinel
  - Cluster

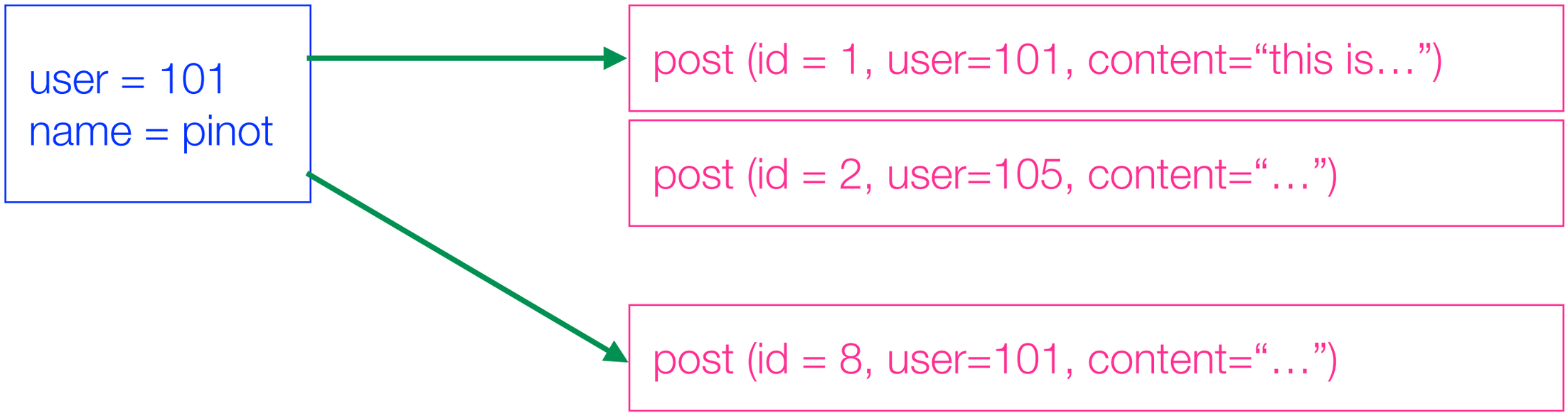


Source: https://architecturenotes.co/redis/

Example: Redis for “X-Like” Datastore

- Create data model for “X-Like”
- Data items
  - Users - id, name, can follow others, can be followed
  - Posts - id, content
- Relationship
  - 1 user can have many posts, each post can associate to only one user
  - User can follow one another

Users and Posts

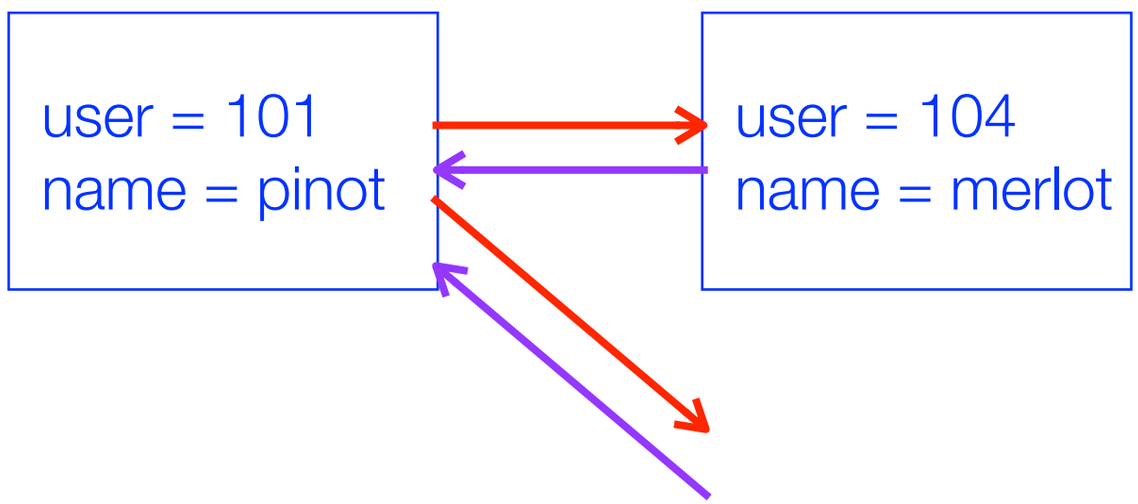



```
HMSET user:101:profile user 101 name "pinot"
SET username:pinot:id 101          # refer back to user-id

HMSET post:1 user 101 content "this is the first post"

RPUSH user:101:post post:1
RPUSH user:101:post post:8
```

Users and Followers




```
SADD user:101:follows 104
SADD user:101:follows 105

SADD user:104:followed_by 101
SADD user:105:followed_by 101
```

Simple Redis-Py Example

For your local redis only

This notebook contains simple redis python commands.

In [1]:
```
import redis
```

Connect to local server -- no hostname or ip is needed

In [2]:
```
rd = redis.Redis(charset="utf-8", decode_responses=True)
```

In [3]:
```
rd.set('user:101:name', 'pinot')
```

Out[3]: True

In [4]:
```
rd.get('user:101:name')
```

Out[4]: 'pinot'

In [5]:
```
rd.hset('post:1', 'user', 101)
rd.hset('post:1', 'content', 'this is the first post')
```

Out[5]: 1

In [6]:
```
rd.hgetall('post:1')
```

Out[6]: {'user': '101', 'content': 'this is the first post'}

In [7]:
```
rd.rpush('user:101:post', 1)
rd.rpush('user:101:post', 8)
```

Out[7]: 2

In [8]:
```
rd.llen('user:101:post')
```

Out[8]: 2

In [9]:
```
rd.lrange('user:101:post', 0, -1)
```

Out[9]:
```
['1', '8']
```

In [10]:
```
rd.sadd('user:101:follows', 104)
rd.sadd('user:101:follows', 105)
```

Out[10]:
```
1
```

In [11]:
```
rd.scard('user:101:follows')
```

Out[11]:
```
2
```

In [12]:
```
rd.smembers('user:101:follows')
```

Out[12]:
```
{'104', '105'}
```

In [13]:
```
cursor = 0
cursor, keys = rd.scan(cursor=cursor, match='user:*')
while cursor > 0:
    for key in keys:
        print('found: ', key)
    cursor, keys = rd.scan(cursor=cursor, match='user:*')

for key in keys:
    print('found: ', key)
```

```
found:  user:101:post
found:  user:101:follows
found:  user:101:name
```

References

- ScaleGrid, “Top Redis Use Cases by. Core Data Structure Types”, https://scalegrid.io/blog/top-redis-use-cases-by-core-data-structure-types/

- Jerry An, “The most important Redis data structures you must understand”, https://medium.com/analytics-vidhya/the-most-important-redis-data-structures-you-must-understand-2e95b5cf2bce

- Brad Solomon, “How to use Redis with python”, https://realpython.com/python-redis/

- M. Yusuf, “Redis Explained”, https://architecturenotes.co/redis/