How I learned to stop worrying and love atomic()

Database integrity fundamentals in Django

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Background

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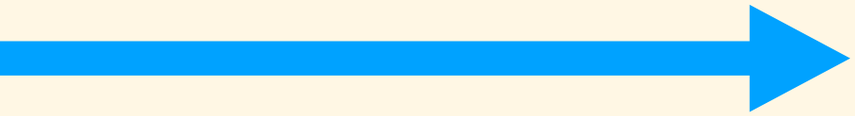
We built OddSlingers.com, a fast, clean online poker experience made with Django + Channels & React/Redux. We learned a lot about database integrity along the way.

Disclaimer: I am not
a distributed systems expert.

I just think they're neat.

It all starts with a single salami slice.

It ends with millions of dollars missing.



Dealing with money

float, Decimal, and math

Avoiding concurrency

linearizing writes in a queue

Dealing with concurrency

transactions, locking, compare-and-swaps

Schema design

log-structured data, minimizing locks

The bigger picture

code layout, storage layer, NewSQL databases

Dealing With Money

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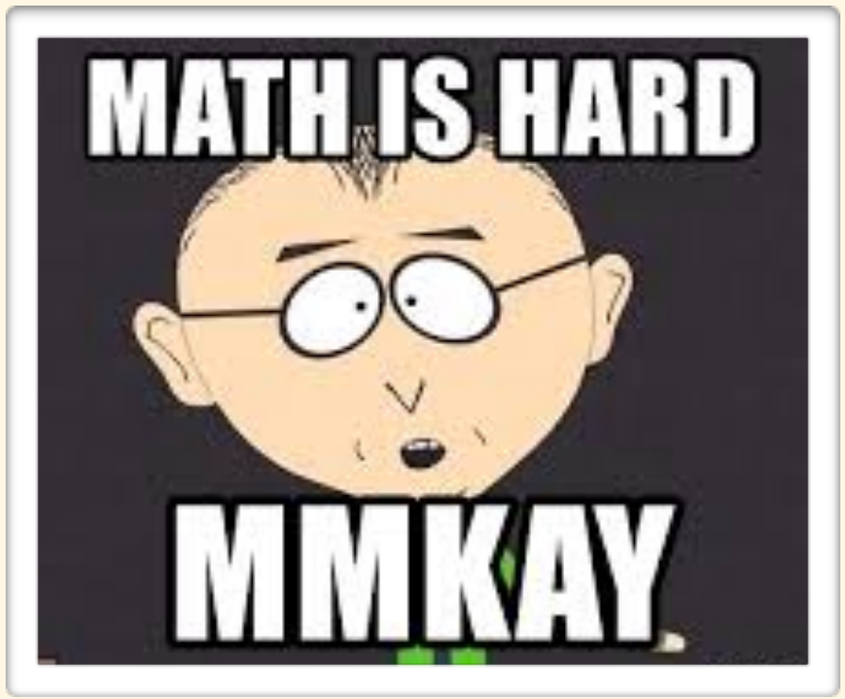

Losing track of fractional cents

(aka salami slicing)

```
class Payout(models.Model):
    ...
    amt = models.DecimalField(max_digits=20, decimal_places=2)

Payout.objects.create(amt=100000/7)
# saves: 14285.71 instead of 14285.714285714
```

Do this 10 million times and suddenly you've lost track of 0.0043 * 10m = $42,857.

I know you're tempted,
don't even try it...
salami slicers all
get caught eventually

float vs Decimal

```
>>> 0.1 + 0.2
0.30000000000000004
```

Floating-point math introduces error that can accumulate.

```
>>> from decimal import Decimal
>>> Decimal('0.1') + Decimal('0.2')
Decimal('0.3')
```

Much better.

Bonkers Rounding (aka Bankers Rounder)

```
>>> round(1.5)
2

>>> round(2.5)
2

>>> round(3.5)
4

>>> round(4.5)
4
```

wat.

Get expected rounding behavior with:

```
>>> decimal.Decimal('2.5').quantize(decimal.Decimal('1'),
                                    rounding=decimal.ROUND_HALF_UP)
Decimal('3')
```

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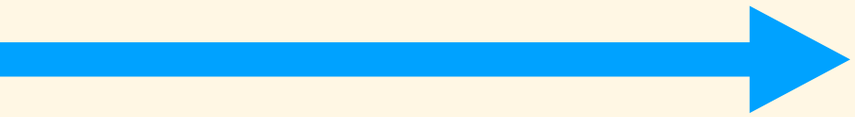

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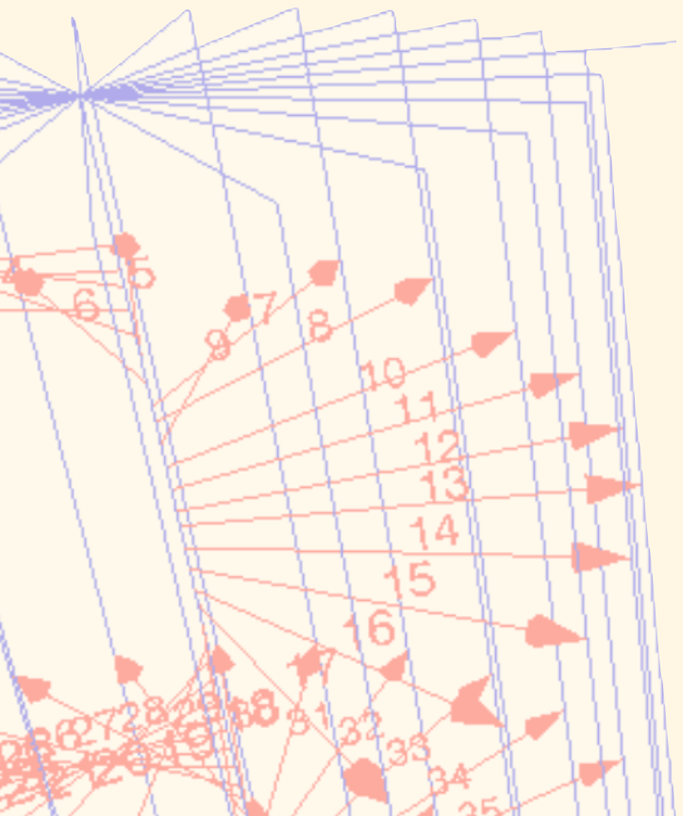
Avoid Concurrency

Eliminate the dragons.

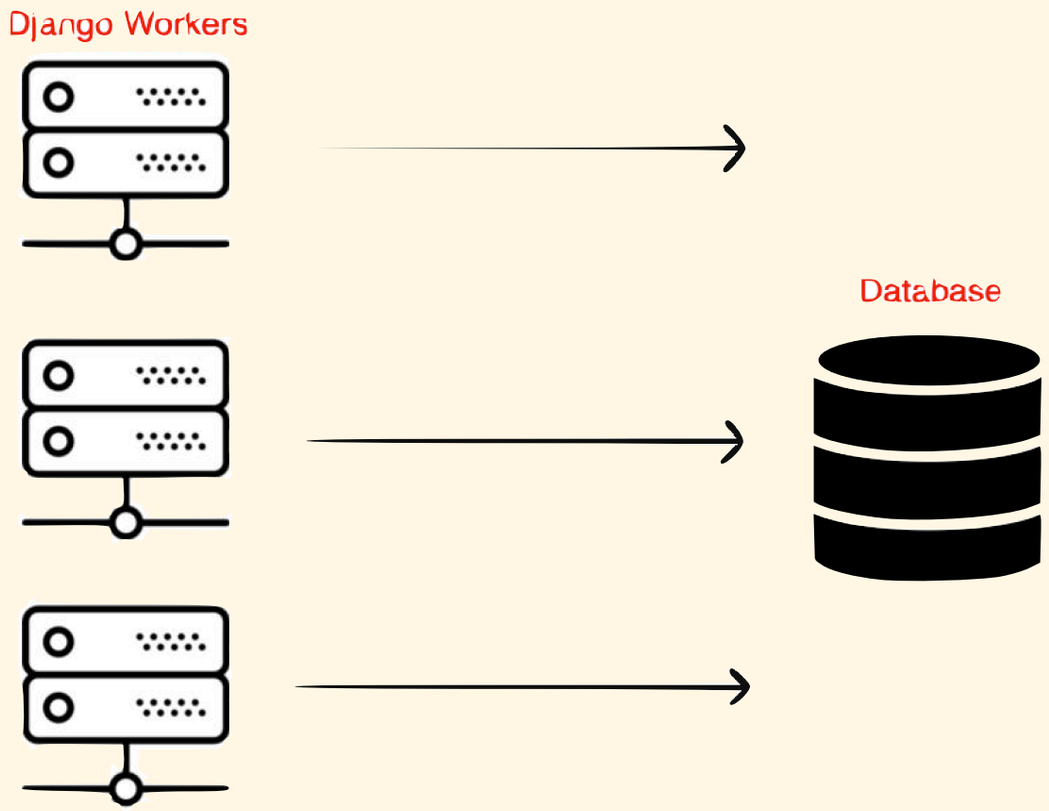


What is a distributed system?

Every Django app.

> Each Django request handler is a separate thread

> What happens when two threads try to do something critical at the same time? e.g. update a user's balance

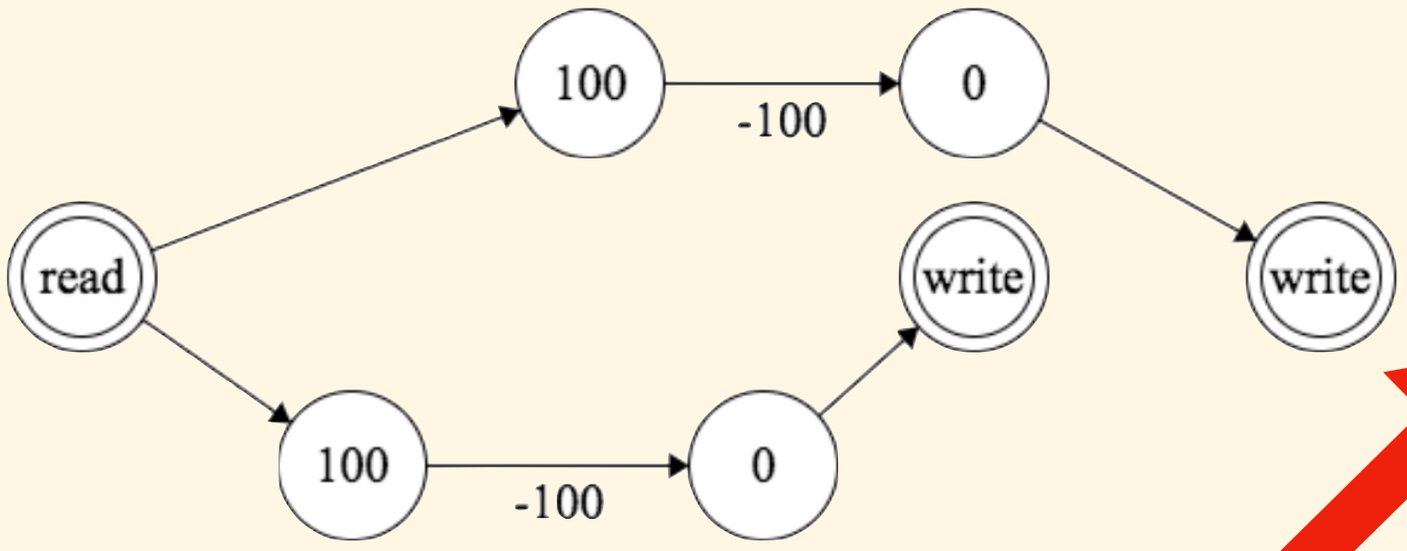


Other threads writing will break the bank

Failure if two threads execute withdrawals at once:

```
if (user.balance == 100) {
    user.balance -= 100  # 2nd thread can .save() a 100 withdrawal befo
    user.save()          # balance is now 0 but should be -100
}
```

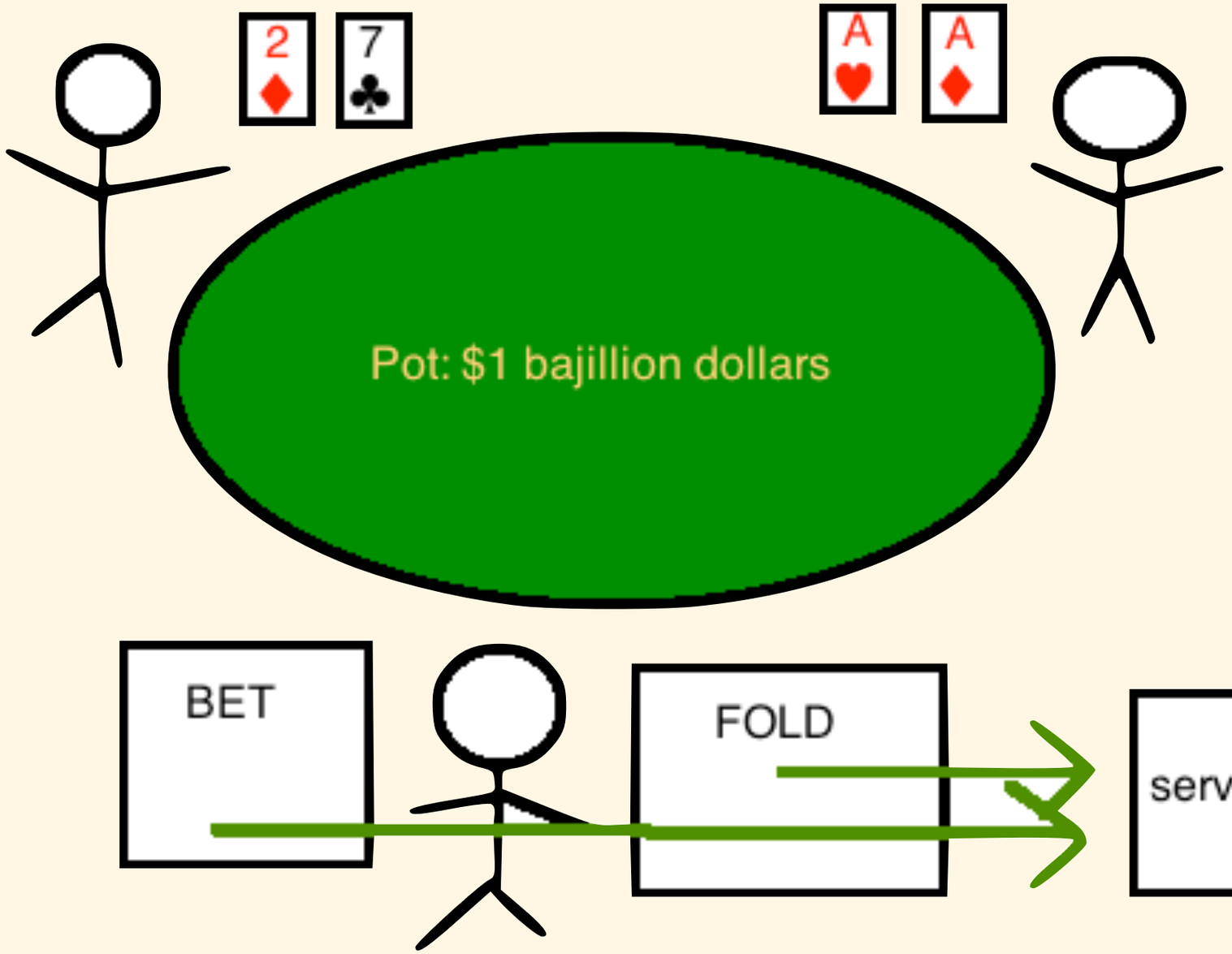
aka “Time of check to time of use”-bug (TOCTTOU).



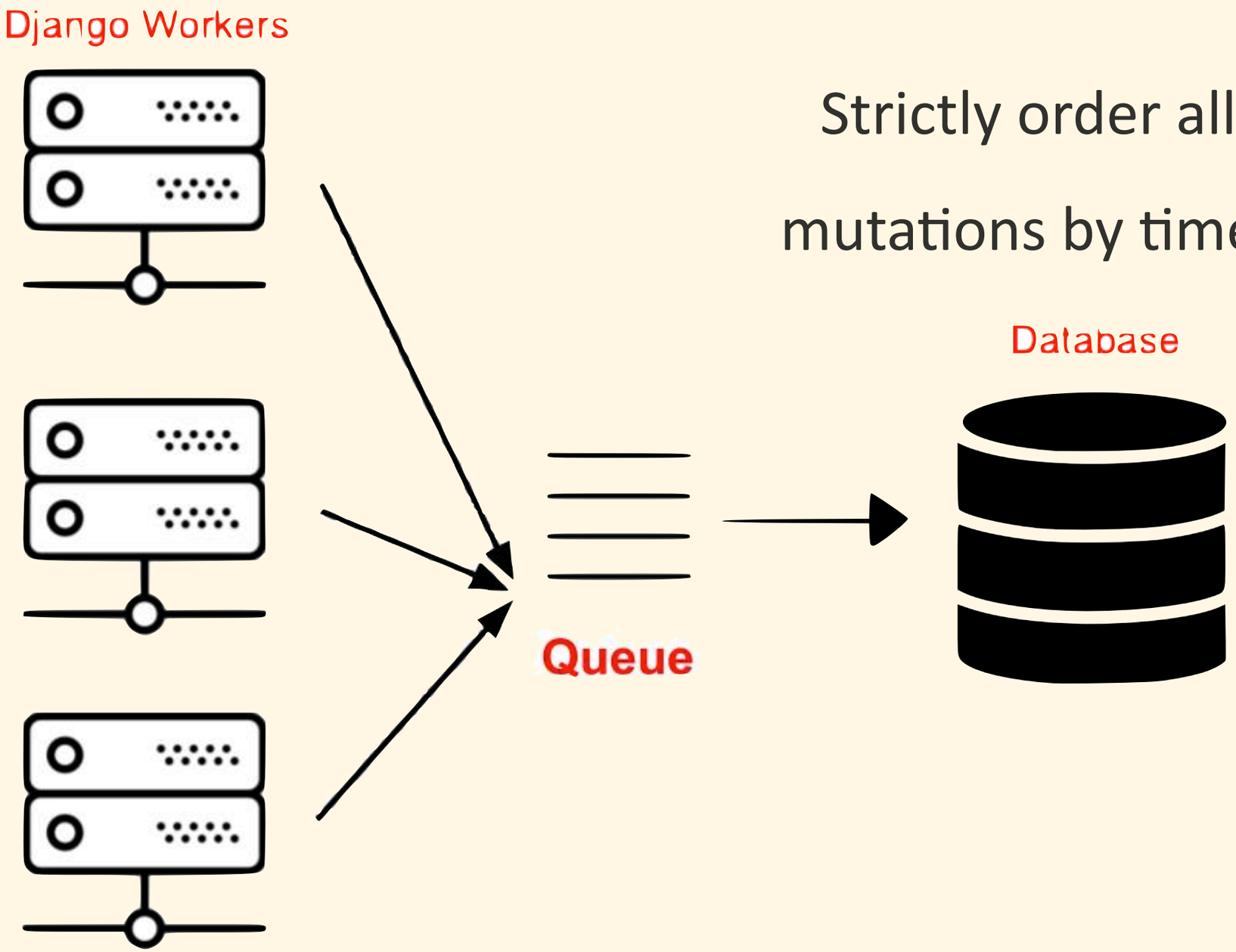
$0 instead of $-100

The Challenge

Dealing with concurrent write conflicts



A solution: remove the concurrency



Strictly order all state mutations by timestamp

Linearize all the writes into a single queue

```
transactions = [
    # timestamp   condition                 action

    (1523518620,  "can_deposit(241)"    ,  "deposit_usd(241, 50)"),
    (1523518634,  "balance_gt(241, 50)",  "buy_chips(241, 50)"),
]
```

If **only one** change happens at a time,

no conflicting writes can occur.

Execute the writes 1 by 1 in a dedicated process

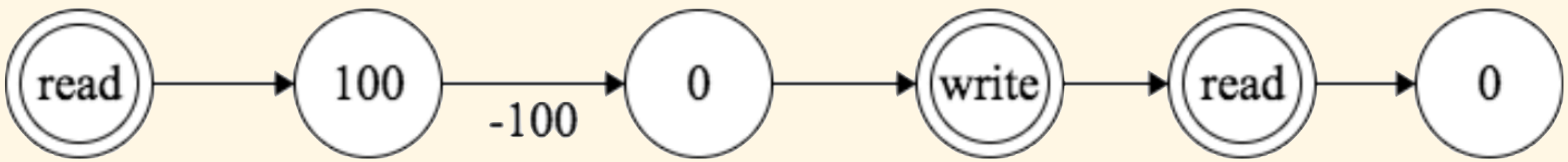
(using a Redis Queue, or Dramatiq, Celery, etc.)

```
while True:
    ts, condition, action = transaction_queue.pop()

    if eval(condition):
        eval(action)
```

Don't let any other processes touch the same tables.

All checks & writes are now *linearized*.



Eliminate concurrency at all costs.

If you value your sanity,
linearize critical transactions into a single queue
whenever possible.

Don't even watch the rest of the talk,
just stop now, really, you probably don't need concurrency...

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Dealing With Concurrency

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I warned you about the dragons...

Tools the ORM provides

> Atomic transactions **transaction.atomic()**

> Locking **Model.objects.select_for_update()**

> Compare-and-swaps **.filter(val=expected).update(val=new)**

Atomic Transactions

```
with transaction.atomic():

    thing = SomeModel.objects.create(...)
    other_thing = SomeModel.objects.create(...)

    if error_condition(...):
        raise Exception('Rolls back entire transaction')
```

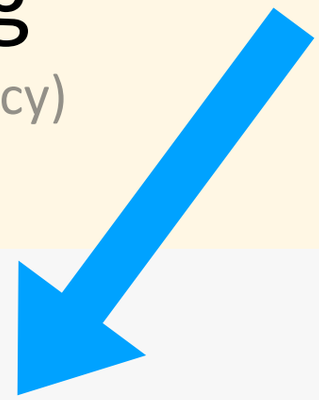
Exceptions roll back the entire transaction block.

Neither object will be saved to the DB.

Transactions can be nested.

Row Locking

(pessimistic concurrency)



```
with transaction.atomic():
    to_update = SomeModel.objects.select_for_update().filter(id=thing.id)
    ...
    to_update.update(val=new)
```

.select_for_update() allows you to lock rows

Locking prevents other threads from changing the row until the end of the current transaction, when the lock is released.

Atomic compare-and-swaps

(optimistic concurrency)

```
last_changed = obj.modified

...

SomeModel.objects.filter(id=obj.id, modified=last_changed).update(val=new_val)
```

Only updates if the db row is unchanged by other threads.

> any modified obj in db will differ from our stale in-memory obj ts
> filter() wont match any rows, update() fails
> overwriting newer row in db with stale data is prevented

This is very hard to get right, locking is better for 90% of use cases!

Hybrid Solution

(optimistic concurrency + pessimistic or Multiversion Concurrency Control)

```
last_changed = obj.modified

... read phase

SomeModel.objects.select_for_update().filter(id=obj.id, modified=last_changed)

... write phase
```

Best of both worlds

> locking is limited to write-phase only
> no need for complex multi-model compare-and-swaps

MVCC is used internally by PostgreSQL

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What is log-structured data?

Append-only tables vs mutable tables

> Mutable example

User	Balance
Alice	52
Bob	21

> Log-structured example (immutable, append-only)

Timestamp	User	Transfer
1500000001	Alice	+100
1500000002	Alice	- 50
1500000003	Bob	+ 2

Totals are derived from sum of rows for a given user

Log-structured storage is a foundational building block of safe, distributed systems.

- Provides strict ordering of writes
- Immutable log of every change
- Ability to revert to any point in time

See: redux, CouchDB, Redis

But log-structured tables make locking hard...

Because any new row added can change the total,

we'd have to lock the entire BalanceTransfer table to prevent concurrent processes from adding new transfers that change the total.

How else can we prevent concurrent writes from changing a user's balance?

Store a total separately from the log,
require they be updated together

```
class UserBalance(models.model):
    user = models.OneToOneField(User)
    total = models.DecimalField(max_digits=20, decimal_places=2)
```

A single-row lock must now be obtained on the **total**
before adding new BalanceTransfer rows for that user.

Full example using locking

```
def send_money(src, dst, amt):
    with transaction.atomic():
        # Lock balance rows, preventing other threads from making changes
        src_bal = UserBalance.objects.select_for_update().filter(id=src)
        dst_bal = UserBalance.objects.select_for_update().filter(id=dst)

        if src_bal[0].total < amt:
            raise Exception('Not enough balance to complete transaction')

        # Update the totals and add a BalanceTransfer log row together
        BalanceTransfer.objects.create(src=src, dst=dst, amt=amt)
        src_bal.update(total=F('total') - amt)
        dst_bal.update(total=F('total') + amt)
```

Side benefit: no need to scan entire BalanceTransfer table anymore to get a user's balance

Log-structured data is great, but...

it requires careful thought to:

- minimize detrimental whole-table locking
- access aggregate values without scanning

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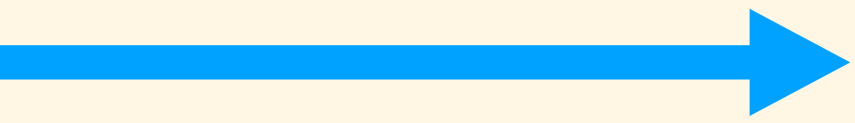

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What happens when the butterflies flip your bits?

Code Layout

> Only perform writes via helper funcs, never update models directly

> Put all transactions in one file for easier auditing & testing

banking/transactions.py:

```
def transfer_money(src, dst, amt):
    with transaction.atomic():
        ...

def merge_accounts(user_a, user_b):
    with transaction.atomic():
        ...

def archive_account(user):
    with transaction.atomic():
        ...
```

```
from banking.transactions import transfer_money

...
```

Storage Layer Concerns

> The database can't guarantee data integrity on its own

> Bit flips are common, use ECC RAM (and ZFS!)

> Streaming replication or snapshots to do offsite-backups

OFFSITE BACKUPS. OFFSITE BACKUPS. SET UP YOUR OFFSITE BACKUPS.
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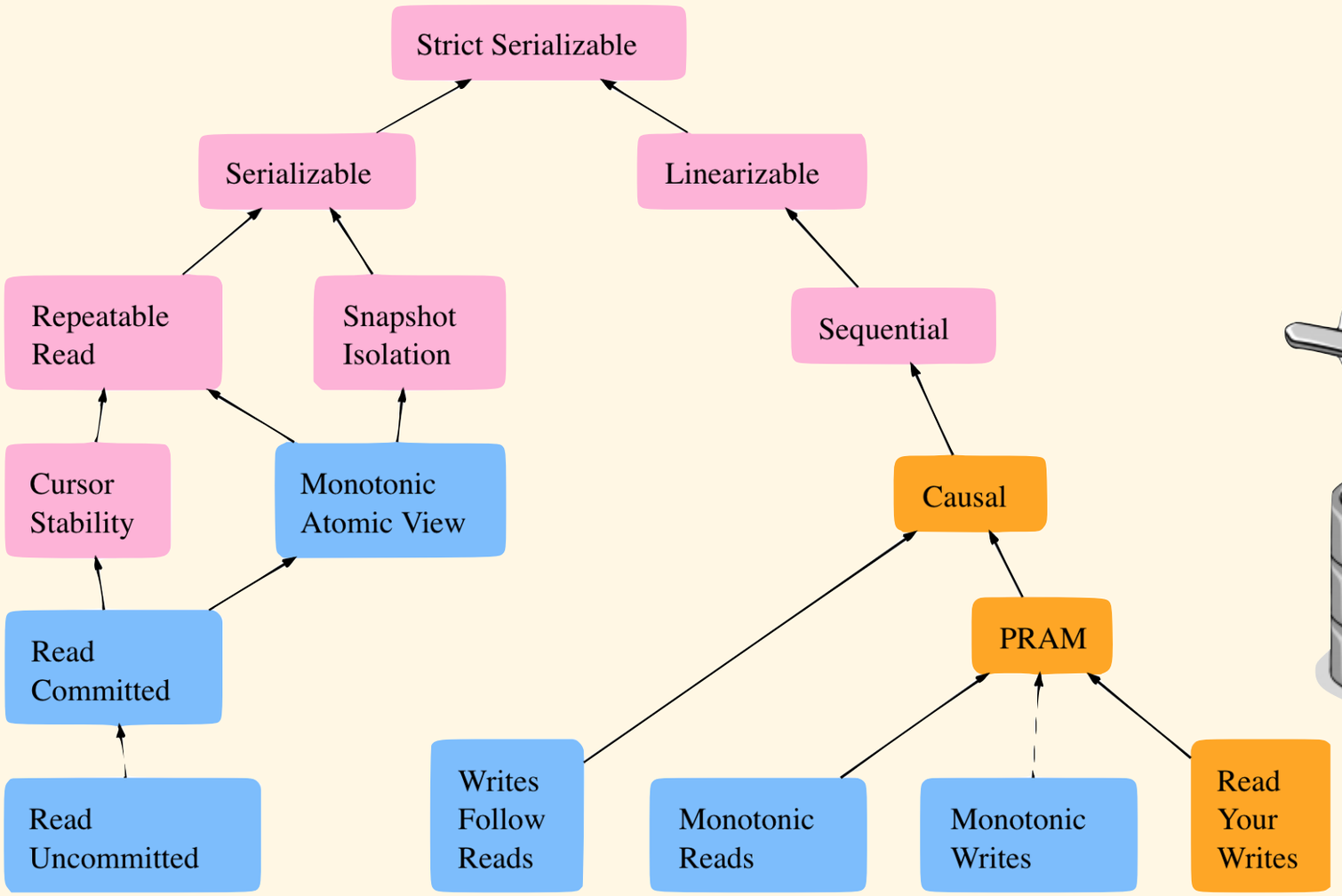
Database Isolation Levels

In some modes, partial transaction state can leak into other threads.

```
DATABASES = {
    'OPTIONS': {
        'isolation_level':psycopg2.extensions.ISOLATION_LEVEL_SERIALIZABLE,
```



Highly complex topic, much more info can be found elsewhere...

It's possible to use a separate database with a higher isolation level for critical data

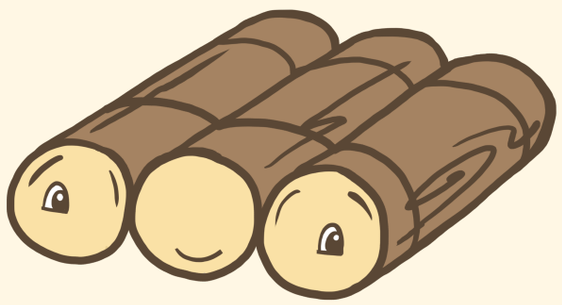
```
with transaction.atomic(using='default'):
    with transaction.atomic(using='banking'):
        MyModel_one(...).save(using='default')
        MyModel_two(...).save(using='banking')
```

Django supports transactions across multiple databases.

What the Future Looks Like

Serializable, distributed SQL without sharding.

SQL on top of >
key:val store on top of >
raft-based log-structured storage




CockroachDB & TiDB work with Python

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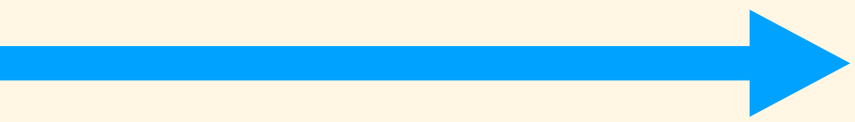

The End

Key takeaways: don't stop worrying, but love atomic()

Don’t use floats.
Don’t use round(), if you must, always account for the remainder.
Don’t execute non thread-safe writes in a parallel environment.

Use `Decimal` instead of `float`, and `Decimal.quantize()` instead of `round()`:

```
Decimal('0.35') + Decimal('100.15')
```

Lock dependent rows during transactions:

```
with transaction.atomic():
    players = Player.objects.filter(user=user).select_for_update()
    user.balance = player_balance_sum(players)
    user.save()
```

Use atomic compare-and-swap operations when you cant lock:

```
User.objects.filter(id=user.id, balance__gt=50)\
            .update(balance=F('balance) - 50)`
```

Q&A

Special thanks to:

Django Core Team & Contributors,
PyGotham Organizers, Andrew Godwin,
Aphyr, Tyler Neely

Final Disclaimer: I'm not qualified to tell you how to
design your distributed system. Get a professional for that.

I can only show you challenges and solutions I've discovered in my personal adventures with Django. Please let me know if you have corrections!

Monadical is hiring remote developers!

Ping me @theSquashSH on Twitter!