Data-intensive applications using microservices

CE290I - Control and information management
Systems Engineering, UC Berkeley

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About me

- Head of Data Science at Car IQ Inc
- 10 years at Portuguese Air Force Academy
- 5 years at Air Force Metrology Lab
- PhD in Systems Engineering, UC Berkeley
- Interested in: DS, DE, AI, ML, mobile robotics, environmental monitoring, digital payments...

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Data-intensive applications

- Applications that process large volumes of data, typically in real time or near-real time
- Examples: recommendation engines, fraud detection, real-time analytics, and scientific research.
- Large heterogeneous stacks, comprised by different services developed by different teams, SW Eng, DE, DS, ML, etc.
- Must meet hard requirements on scale, performance, and security
- Microservices architectures have been widely adopted for data-intensive applications

Why not Monoliths?!

Everybody used to love them!

Source: 2001: a space odyssey

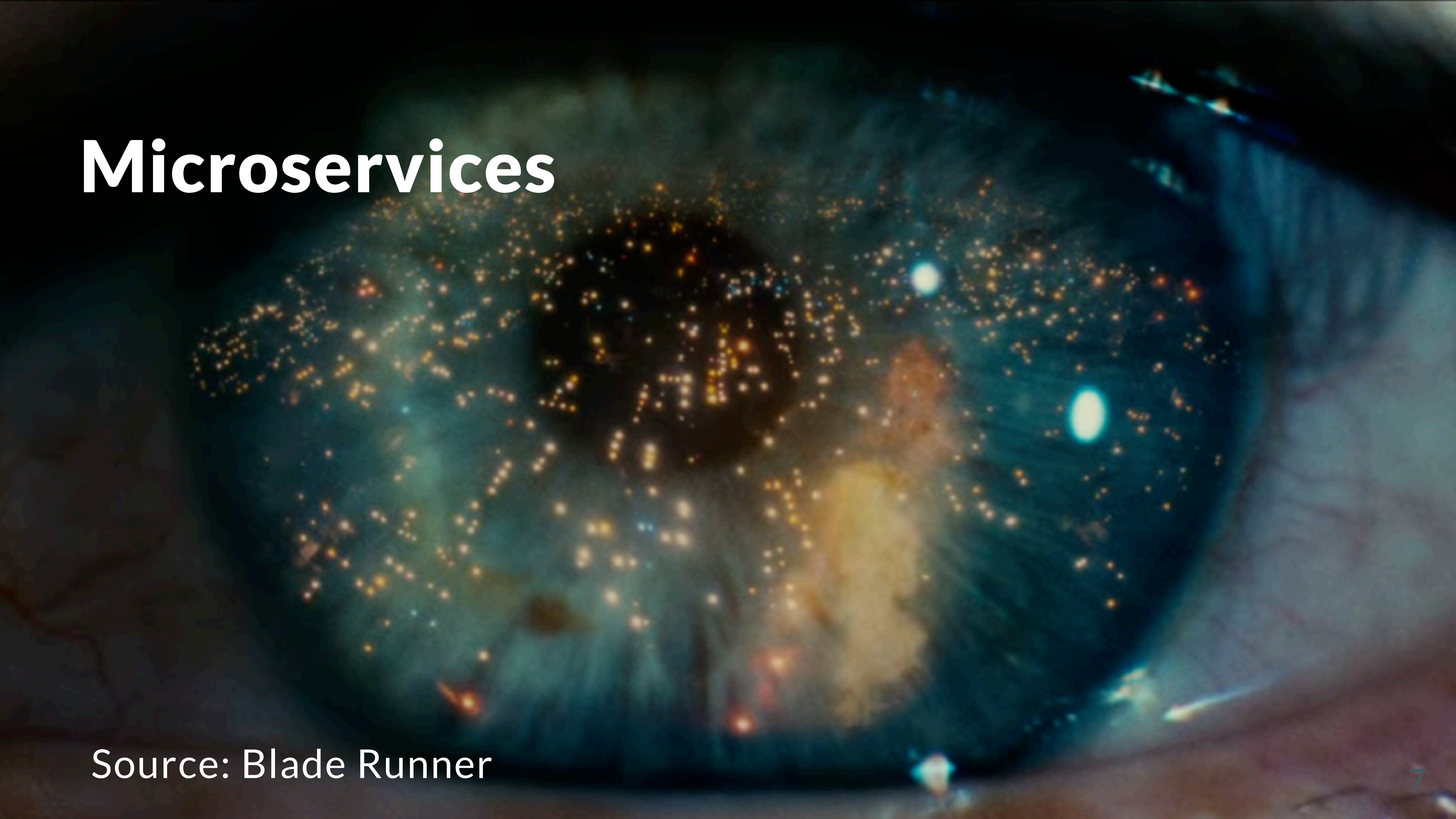
Monolithic Architectures: the good

- Traditional software architecture
- All the components are tightly integrated and packaged together
- Application is built, deployed, and scaled as a single unit
- Single codebase
- Small dev footprint: programming languages, tools, and platforms
- Easy to deploy
- Easy to document
- Easy to understand

Monolithic Architectures: the bad

- Difficult to maintain as the application grows in size and functionality
- Difficult to handle legacy code
- Difficult to introduce new features
- Developers need to understand in depth the overall application
- The entire application needs to be scaled together
- Any changes or updates require redeploying the entire application

Microservices



Source: Blade Runner

Microservices Architectures

- Independently developed, deployed, and managed
- Easy to maintain and evolve
- Scalable and reliable
- Containerization makes them agnostic to the infrastructure
- Easy to deploy in the cloud
- Flexible and agile

Why using containers?

- **Isolation**: Allows each microservice to run in its own container, ensuring that services are isolated from each other
- **Scalability**: Can be easily scaled up or down to meet demand. Microservices can be replicated or replaced independently
- **Portability**: Ensure that microservices can run consistently across different environments. No more “it works on my machine.”
- **Consistency**: Guarantees the same runtime environment everywhere (local machines, servers, cloud, etc).

Why using containers?

- **Automation and CI/CD**: Integrates seamlessly with continuous integration and continuous deployment pipelines, enabling automated testing, building, and deployment of microservices.
- **Efficient Resource Utilization**: Docker containers are lightweight, allowing multiple microservices to run on the same host efficiently without significant overhead.
- **Simplified Management**: Orchestrators like Kubernetes help manage and deploy microservices at scale, providing features like load balancing, service discovery, and automatic scaling.

Docker containers

- Platform for building, shipping, and running containerized applications.
- It uses lightweight containers that are portable and isolated, making them easy to deploy and scale.
- Docker containers share the operating system kernel, but run as isolated processes, which makes them efficient and secure
- Docker is a popular choice for running applications in production
- Docker can be used to run a wide variety of applications, including web applications, databases, and microservices.

The Simplest Microservice

- Listener: receives and prints messages sent by publishers
- Publishers: send messages to the listener

- Clone the git repo
  - https://github.com/eloipereira/ce290i-microservices
- Navigate to `simplest-microservice` and follow the instructions in `README.md`

Listener and Publisher Dockerfiles

```
# dockerfile.listener
FROM alpine:latest
RUN apk add --no-cache socat
CMD ["sh", "-c", "socat TCP-LISTEN:12345,reuseaddr,fork -"]
```

```
# dockerfile.publisher
FROM alpine:latest
RUN apk add --no-cache socat
ENV PUB_NAME="Publisher"
CMD ["sh", "-c", "while true; do echo \"Hello from ${PUB_NAME}! $(date)\"; sleep 1; done | socat - TCP:listener:12345"]
```

Build and run

```
> docker build -t listener -f dockerfile.listener .

> docker build -t publisher -f dockerfile.publisher .

> docker network create my-network

> docker run --rm --name listener --network my-network -t listener

> docker run --rm --name publisher1 --network my-network -t publisher

> docker run --rm --name publisher2 --network my-network -t publisher
```

Docker compose

- Command-line tool for defining and running multi-container Docker applications
- Takes a YAML file defining and configuring the services of your application, builds and runs all the services
- Docker Compose makes it easy to define and manage complex multi-container applications
- It also makes it easy to share your applications with other developers or deploy them to production

docker-compose.yml

```yaml
services:
  listener:
    build:
      context: .
      dockerfile: ./dockerfile.listener
    container_name: listener
    networks:
      - my-network
  publisher1:
    build:
      context: .
      dockerfile: ./dockerfile.publisher
    container_name: publisher1
    networks:
      - my-network
    depends_on:
      - listener
...
```

docker-compose.yml

```yaml
...
  publisher2:
    build:
      context: .
      dockerfile: ./dockerfile.publisher
    container_name: publisher2
    networks:
      - my-network
    depends_on:
      - listener
networks:
  my-network:
    driver: bridge
```

Client-service REST Microservices

- REST (Representational State Transfer) is a set of architectural principles for designing networked applications based on HTTP
- REST Microservices communicate with each other over HTTP, using HTTP methods (i.e., GET, POST, PUT, and DELETE)
- They exchange data in a lightweight format such as JSON or XML

REST-based GPS Replayer

- Backend microservice
  - Real-time replayer
  - Cache to share state
  - REST API for serving current values
- Frontend microservice
  - Web app requests current values and displays them

Building and running

- Clone the git repo
  - https://github.com/eloipereira/ce290i-microservices
- From your favorite CLI:
  - Build: `docker compose -f docker-compose-rest.yml build`
  - Run: `docker compose -f docker-compose-rest.yml up`
  - Stop: `docker compose -f docker-compose-rest.yml down`
- Open streamlit app: http://localhost:8501/

REST API

- REST API documentation at http://localhost:8000/docs
- GET /gps_state

```
curl http://localhost:8000/gps_state
```

- GET /compute_avg_speed

```
http://localhost:8000/compute_avg_speed?time_window_seconds=10
```

REST API: non-blocking

- POST /request_to_compute_avg_speed

```
curl -X 'POST'
http://localhost:8000/request_to_compute_avg_speed?
time_window_seconds=10
```

- GET /get_avg_speed_task_status

```
http://localhost:8000/get_avg_speed_task_status?task_id=<uuid>
```

Event-driven microservices

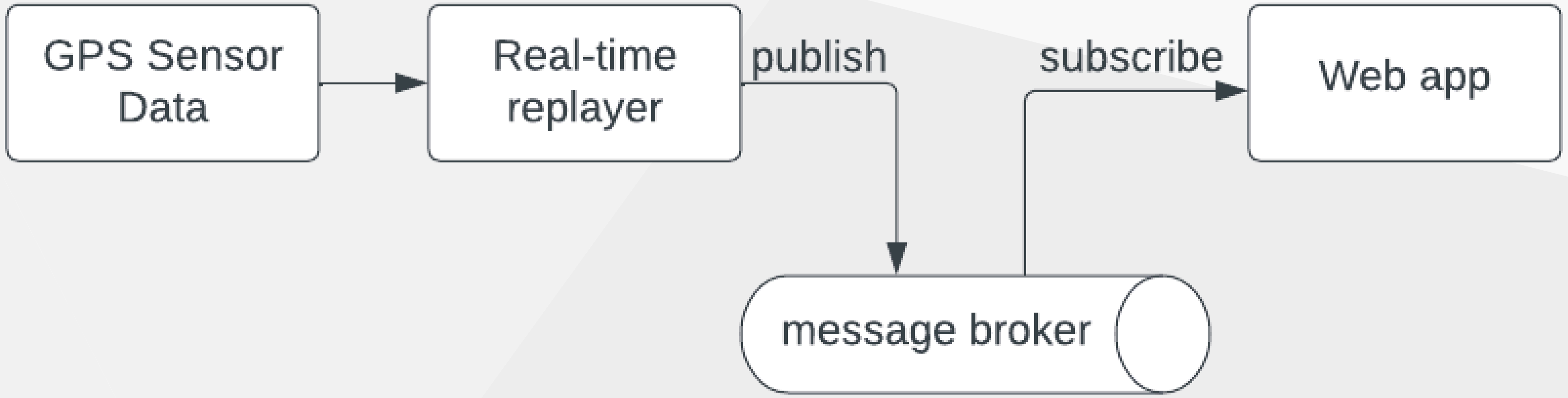
- In event-driven microservices, services communicate and interact with each other by sending messages or reacting upon messages being received
- This architecture allows for asynchronous communication between services, where services can react to events in real-time
- It also enables scalability and fault tolerance, as services can be added or removed without impacting the overall system

Publish-subscribe (pub-sub)

- Asynchronous communication pattern where senders, known as **publishers**, send messages to a message broker.
- The broker then distributes or broadcasts these messages to multiple receivers, known as **subscribers**
- Publishers do not need to have knowledge of the subscribers
- Publishers and subscribers communicate through topics or channels

Event-driven GPS Replayer

- Redis as pub-sub broker
- GPS replayer service publishes to the redis broker on a topic named `gps_state`
- Streamlit web app subscribes to the `gps_state` topic and reacts upon any message received



Building and running

- From your favorite CLI:
  - Build: `docker compose -f docker-compose-pubsub.yml build`
  - Run: `docker compose -f docker-compose-pubsub.yml up`
  - Stop: `docker compose -f docker-compose-pubsub.yml down`
- Open streamlit app: http://localhost:8502/

Conclusion

- Data-intensive applications process large volumes of data and have hard requirements on scale, performance, and security
- They have often large heterogeneous stacks, developed by different teams, such as SW eng, DE, DS, ML, etc
- Microservices architectures have been widely adopted for data-intensive applications
- REST APIs are used whenever the client needs data per request
- Event-driven applications are used whenever the client must react to events in real-time

Development Tools

- Git: distributed version control system
- Docker: platform as a service
- Python, Version: 3.12: programming language
- FastAPI: API web framework
- Pydantic: data validation
- Uvicorn: web server
- Streamlit: App web framework
- Redis: in-memory database and message broker

Development tools (optional)

- Pyenv: Python version management
- VSCode: Editor
- Pylance: python support for VSCode
- Flake8: linter
- Black: formatter
- Pre-commit: code validation
- Marp to build this presentation