Distributed Edge Communication using Python-ZeroMQ

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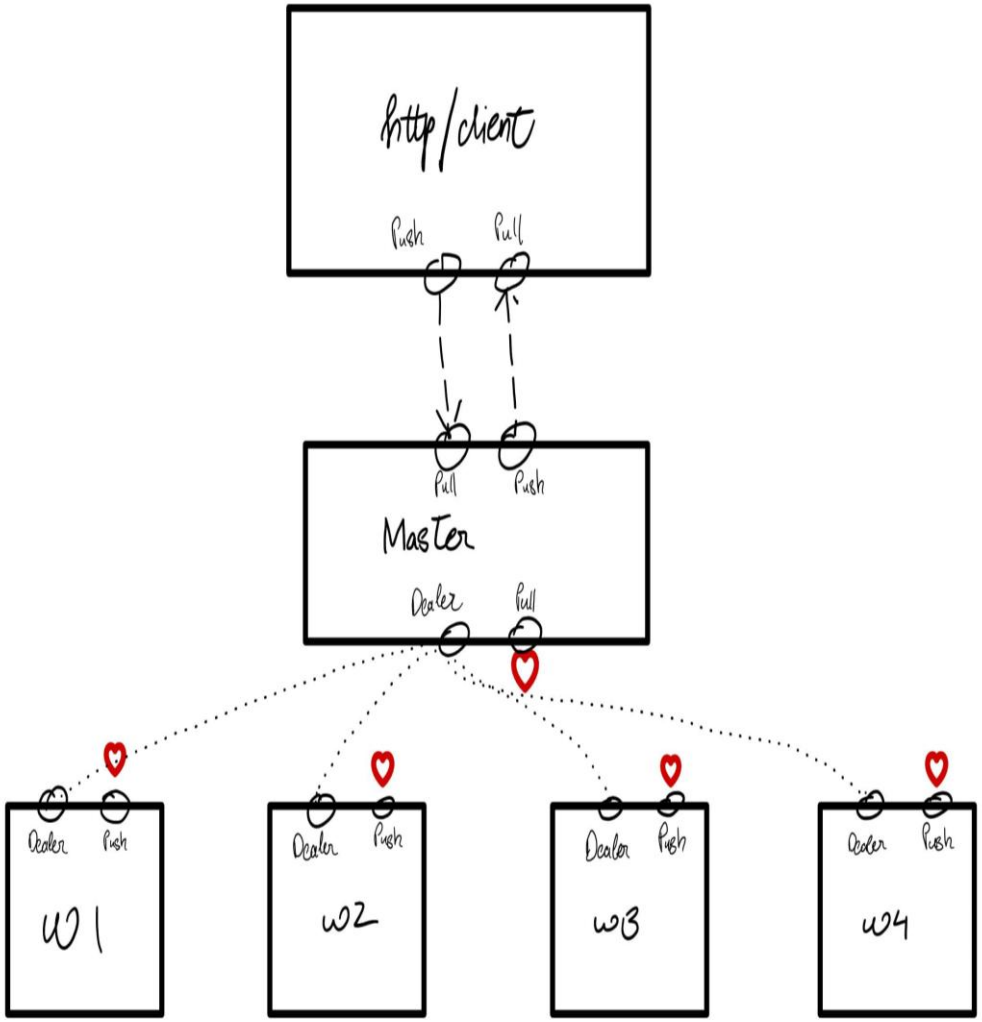
Distributed edge computing system design

Understanding Patterns, Use Cases, and Internal Implementation

System Achitecture



Message format at each socket connection:

- Client →Master (via client_sender PUSH socket)

  Format: JSON request

  {
  "task_id": "<unique_task_id>",
  "task": "grayscale" | "edge",
  "image": "<base64_encoded_image_data>"
  }

  task_id : Unique ID generated by client

  task : type of processing requested

  image: Base64-encoded JPG image

Message format at each socket connection:

- Master →Client (via client_responder PUSH socket)

  Format: JSON request

  {

  "task_id": "<unique_task_id>",

  "task": "grayscale" | "edge",

  "image": "<base64_encoded_processed_image_data>"

  }

  task_id : Unique ID generated by client

  task : type of processing requested

  image: Processed image in Base64-encoded JPG format

Message format at each socket connection:

- Master →Worker (via worker_sender DEALER socket)

  Format: JSON request

  ```
  {
    "task_id": "<unique_task_id>",
    "task": "grayscale" | "edge",
    "image": "<base64_encoded_processed_image_data>"
  }
  ```

  Master simply forwards the request from client to any available worker.

Message format at each socket connection:

- Worker → Master (via worker_socket Dealer socket)

  Format: JSON request

  ```
  {
    "task_id": "<unique_task_id>",
    "task": "grayscale" | "edge",
    "image": "<base64_encoded_processed_image_data>"
  }
  ```

  - Worker sends back the result to the master.
  - Master forwards this directly to the client.

Message format at each socket connection:

- Worker → Master (heartbeat via PULL socket)

  Format: JSON request

  {

  “worker_id": "<worker-xyz>",

  “timestamp": current_unix_timestamp

  }

  - Sent every 2 seconds to let master know worker is alive
  - Master monitors last-seen times to detect timeouts.

ZeroMQ Messaging Patterns in Python

Understanding Patterns, Use Cases, and Internal Implementation

What is ZeroMQ?

- High-performance asynchronous messaging library

- Abstracts socket-level details into messaging patterns

- Enables scalable, distributed systems

- Used via pyzmq in Python

Messaging Patterns Overview

• REQ / REP – Request/Reply

• PUB / SUB – Publish/Subscribe

• PUSH / PULL – Pipeline pattern

• ROUTER / DEALER – Advanced async messaging

• PAIR, STREAM, XPUB/XSUB – Other patterns

REQ / REP Pattern

- Description: Synchronous client-server request-reply
- Use Case: RPC, simple question-answer systems
- Backend: Strict send-receive alternation, ordered responses

PUB / SUB Pattern

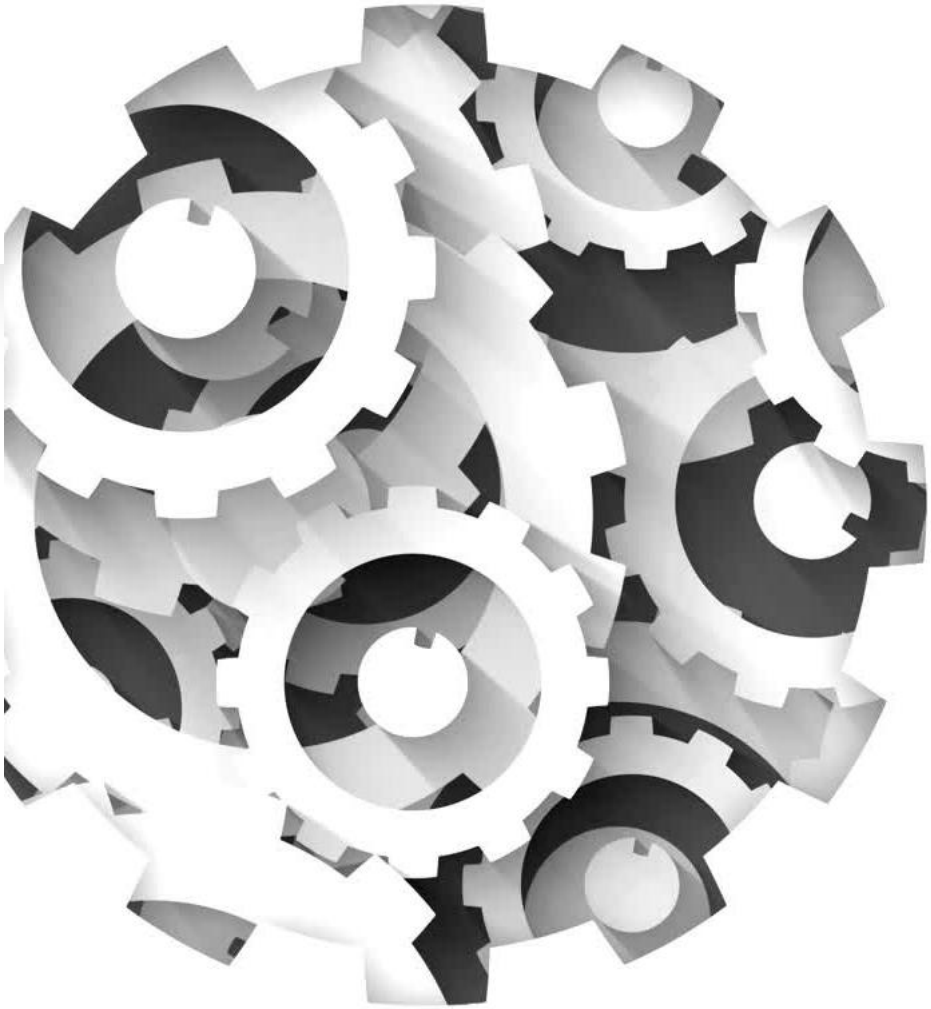
- Description: Asynchronous publish-subscribe based on topics
- Use Case: Real-time feeds, sensor broadcasting, IoT
- Backend: Topic filtering, publisher unaware of subscribers

PUSH / PULL Pattern

- Description: One-way pipeline for load-balanced distribution
- Use Case: Task queues, load-balanced workers
- Backend: Round-robin scheduling, separate worker queues

Round-Robin Fashion

- • Round-robin is a method to distribute tasks in a circular order
- • Each worker receives messages one-by-one in sequence
- • Used in PUSH/PULL to balance load across multiple PULL sockets
- • Example: Worker1 → Worker2 → Worker3 → Worker1 → ...



ROUTER / DEALER Pattern

- Description: Advanced async many-to-many messaging
- Use Case: Custom brokers, proxies, advanced routers
- Backend: ROUTER tracks identities, DEALER is async and non-blocking

How ZeroMQ Works Internally

- Socket abstraction over OS-level sockets
- Queues per connection
- IO threads manage messaging
- Fair queueing, load balancing
- Automatic reconnects, retries

Queue Size in ZeroMQ

- • Each socket in ZeroMQ maintains an internal message queue
- • Default high water mark (queue limit) is 1000 messages per socket
- • Can be configured using socket options:
- - ZMQ_SNDHWM: Send queue size
- - ZMQ_RCVHWM: Receive queue size
- • If the queue is full, ZeroMQ blocks or drops messages (depending on config)

Summary of Patterns

- • REQ/REP: Bidirectional, synchronous (Client-server)
- • PUB/SUB: One-to-many, async (Broadcasting)
- • PUSH/PULL: One-to-many, async (Task queues)
- • ROUTER/DEALER: Many-to-many, async (Proxies, routers)

Efficiency and Fault Tolerance

- - Master removes unresponsive workers automatically
- - Clients wait asynchronously (no blocking)
- - Threaded master handles task, result, heartbeat separately
- - Scalable: add more workers/clients easily

Project Highlights

- - Web-based interface for multiple users
- - Distributed processing with ZeroMQ
- - Heartbeat monitoring for fault detection
- - Asynchronous design using threading and events
- - Real-time image processing using OpenCV

Final Review Objectives:

- To fix an obvious bug where the request data is not being handled properly.
- To Add support for broadly used Image processing tasks and sequential processing.
- To add Client side authentication.
- Caching and user history
- To demonstrate distributed nature using RasPy/Esp/microcontrollers.

Thank you