Image Search with Kafka, S3, Elastic, and LLMs

Giulia Cuppoletti, Alec Davis, Isabella Staley

HPCCEA 2025

Prepared by LLNL under Contract DE-AC52-07NA27344.

Meet the team

Giulia Cuppoletti
Major: Computer Science
School: Penn State
Year: Recently graduated

Alec Davis
Major: Computer Science
School: BYU
Year: Senior

Isabella Staley
Major: Information Technology
School: Wayne State University
Year: Junior

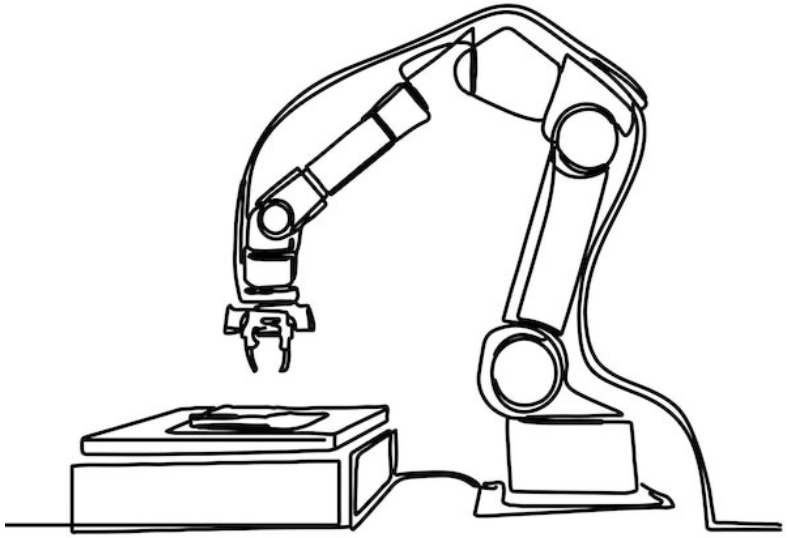
What did we want to build?

An image search engine that could:

- Search images based on key features
- Quickly yield search results from many images
- Have a pipeline that could be spread across multiple compute nodes/clusters

Why did we want to build it?

- Proof of concept for clients using automated lab equipment
  - Many pictures taken autonomously
  - Need for analysis/categorization of pictures
  - Wanted ability to search through pictures
- Explore interaction of Kafka, Elastic, and S3 on clusters



Technologies We Used

Apache Kafka

- Data streaming
- Consumers and Producers
- Can be distributed across nodes/clusters

NetApp Storage Grid

- Imitates S3 (Simple Storage Service)
- Stores objects in buckets
- Objects available through URL

Elasticsearch

- Powerful search engine
- Stores data in indexes
- Allows for complex queries (keywords, filters, etc.)

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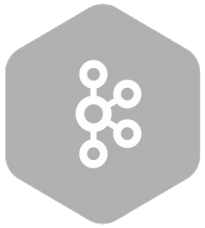

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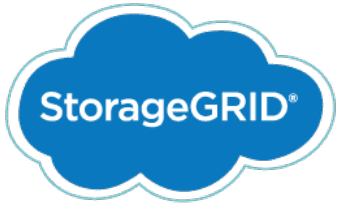

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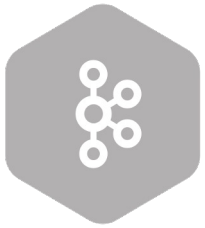

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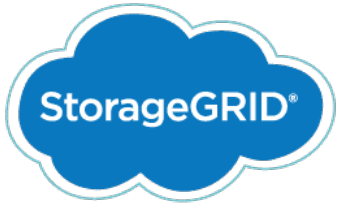

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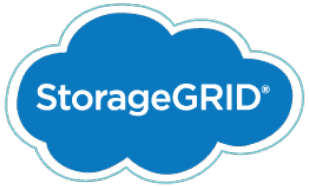
How We Did It

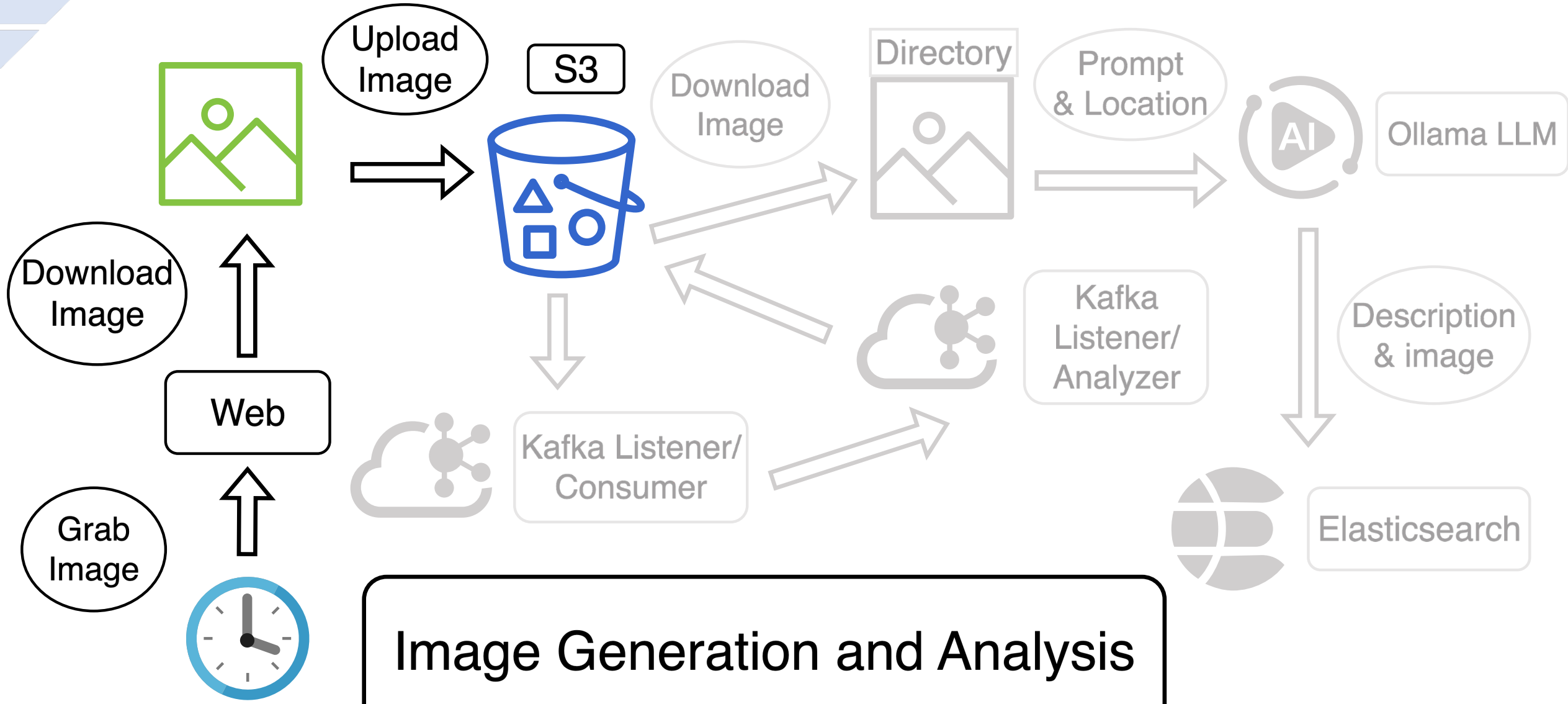
Set Up

- Kafka Container
- NetApp Storage Grid
- Elasticsearch
- Ollama (OpenShift)
  - Llama 4 Scout



Implementation Workflow

1. Image Generator
2. Image Consumer
3. Image Analyzer
4. Website
5. Query Tool
6. Webpage Generator


Upload Image
S3
Download Image
Directory
Prompt & Location
AI
Ollama LLM
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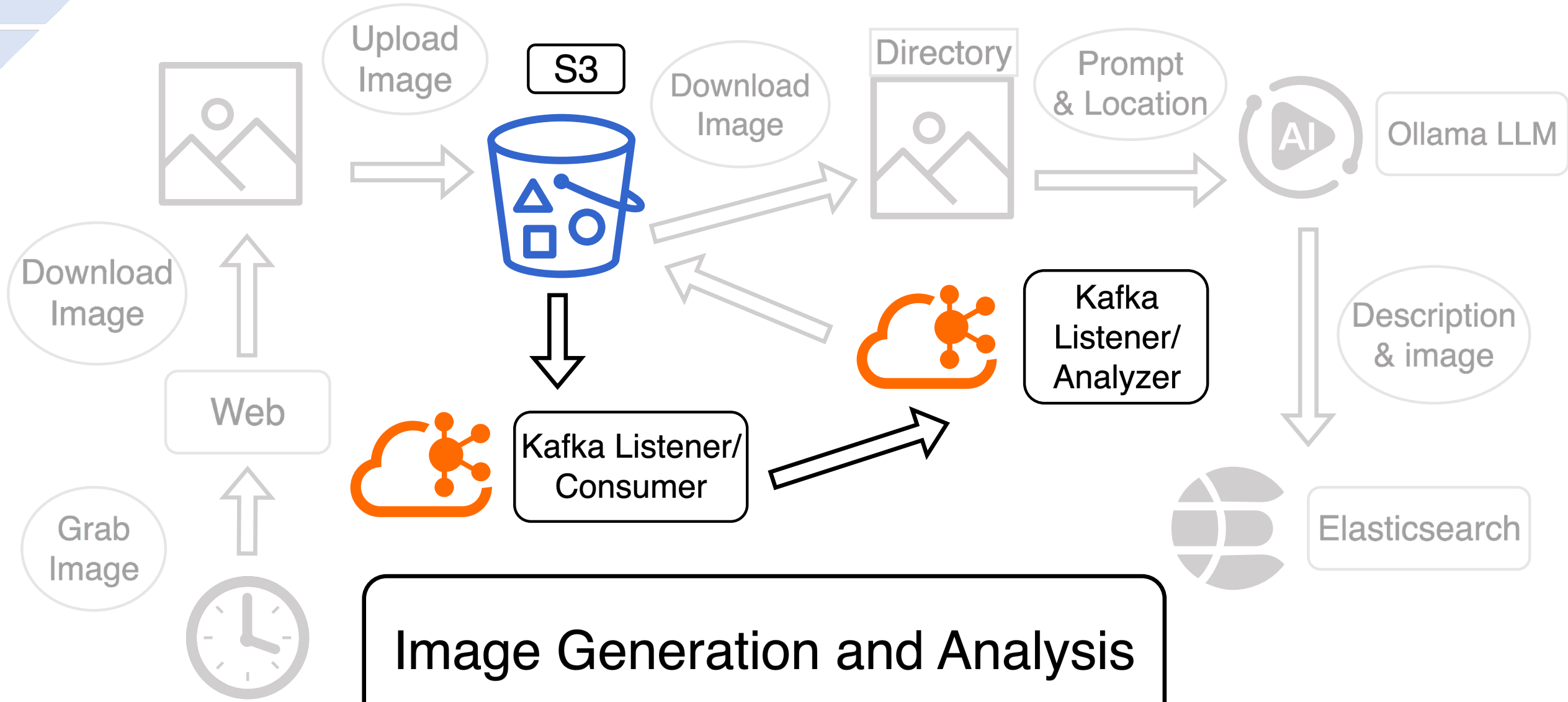
Web
Kafka Listener/ Analyzer
Description & image
Kafka Listener/ Consumer
Elasticsearch
Grab Image
Image Generation and Analysis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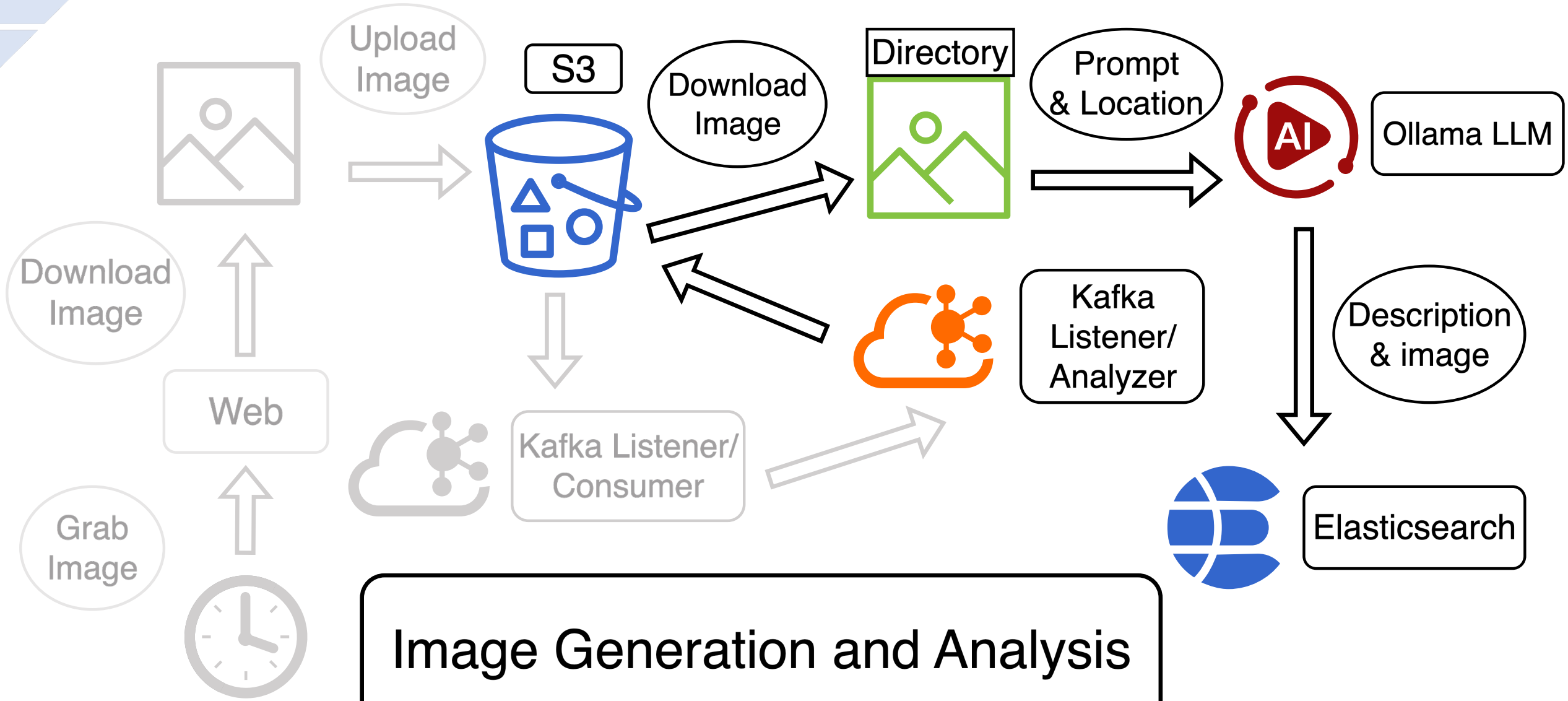
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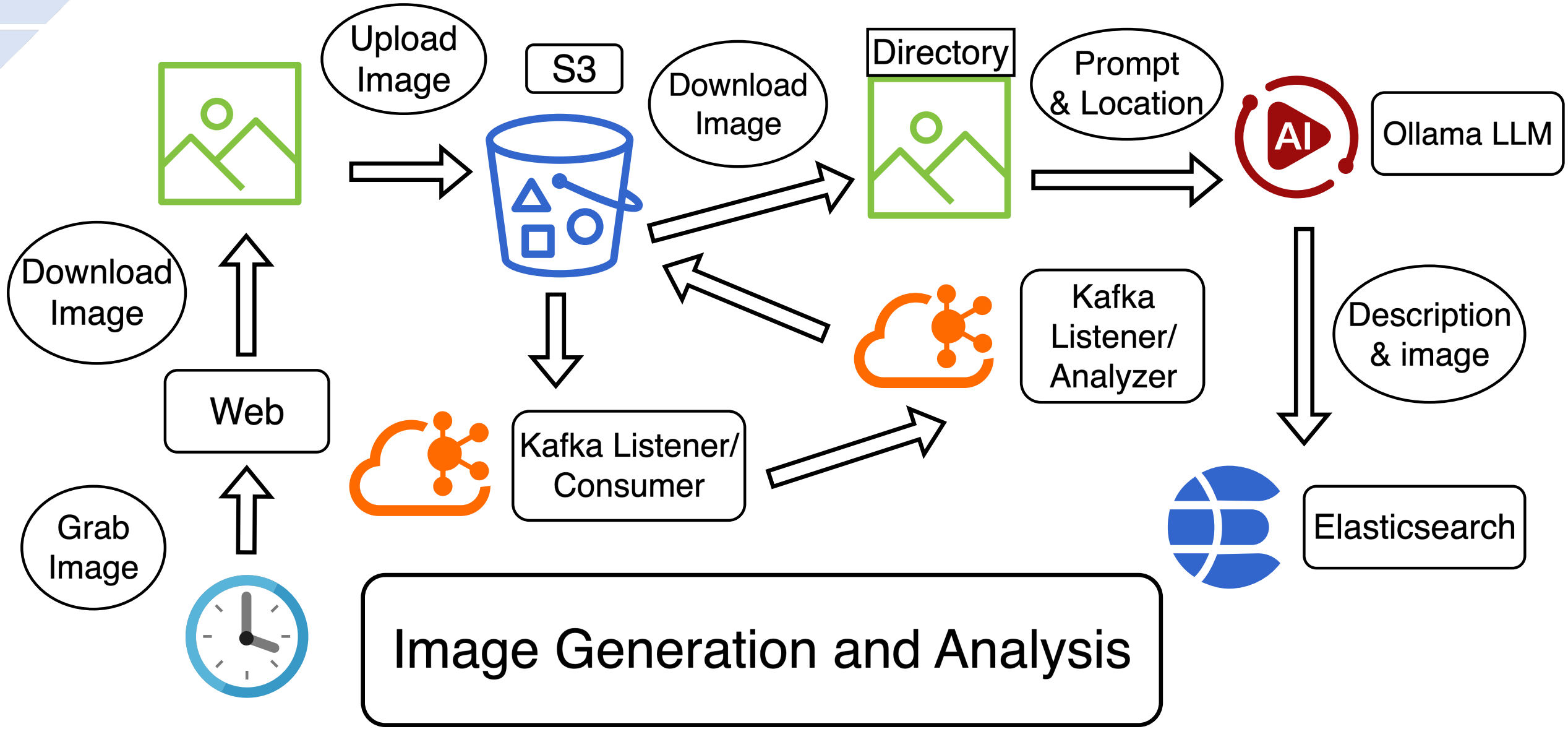
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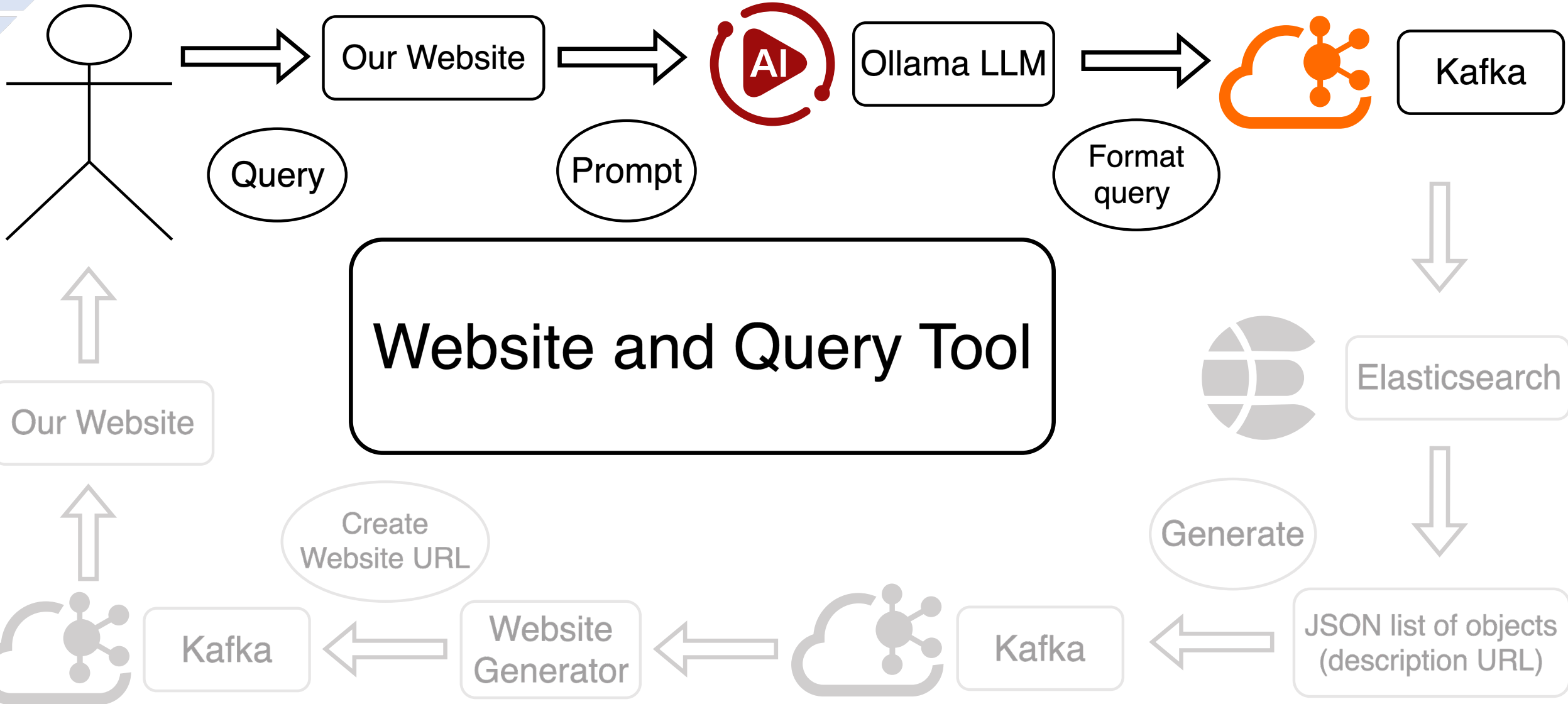
Our Website
Ollama LLM
Kafka
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Format query
Website and Query Tool
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Create Website URL
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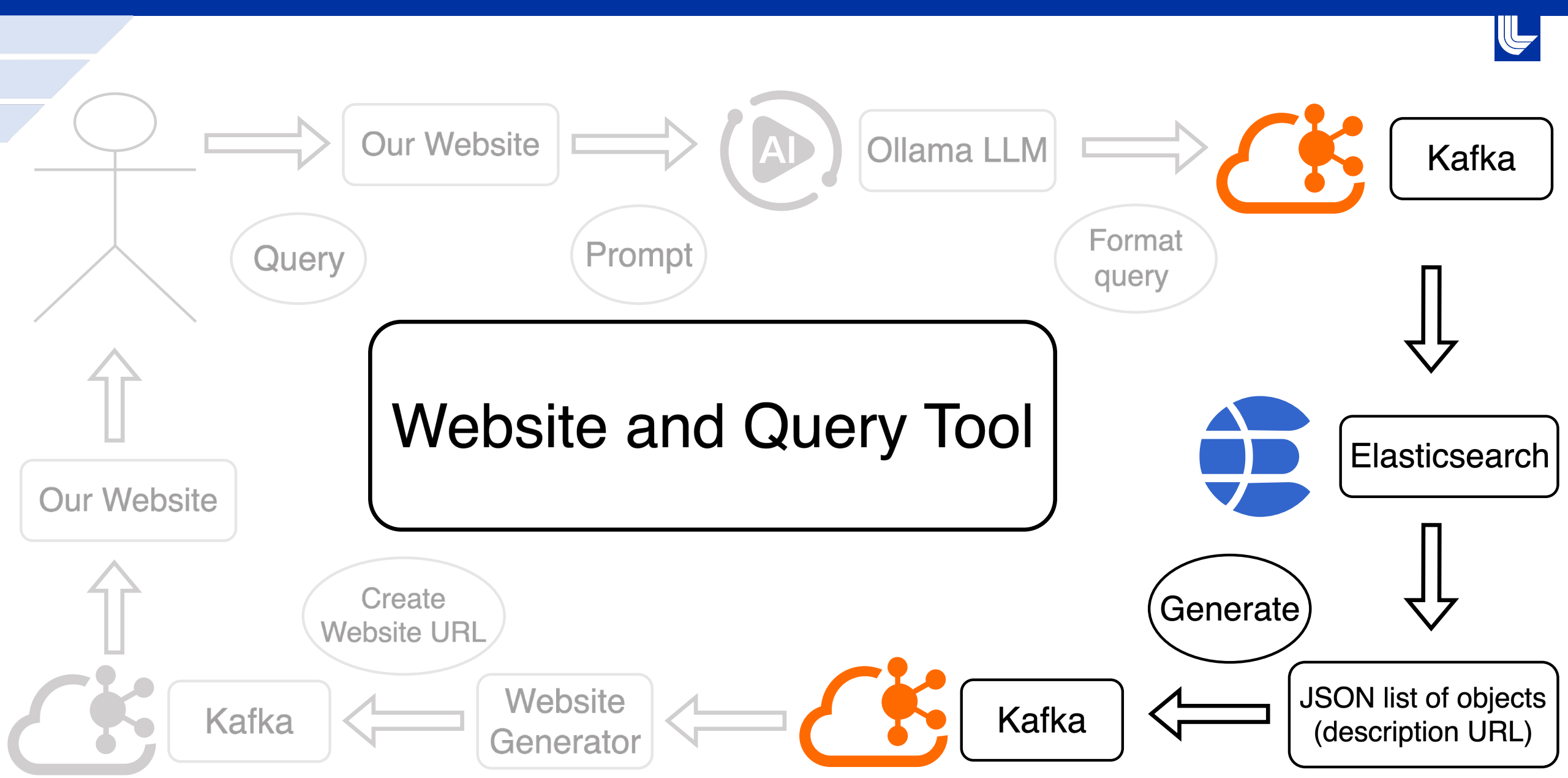
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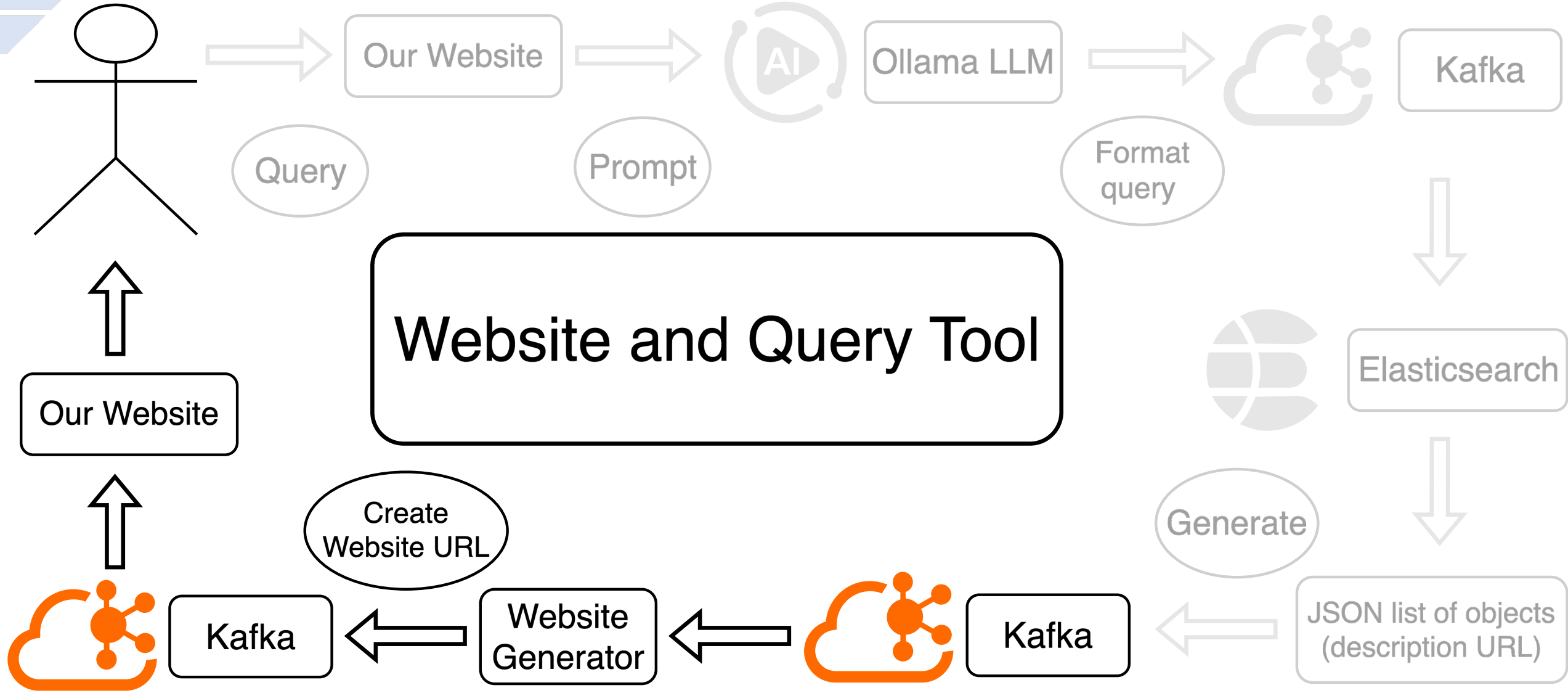
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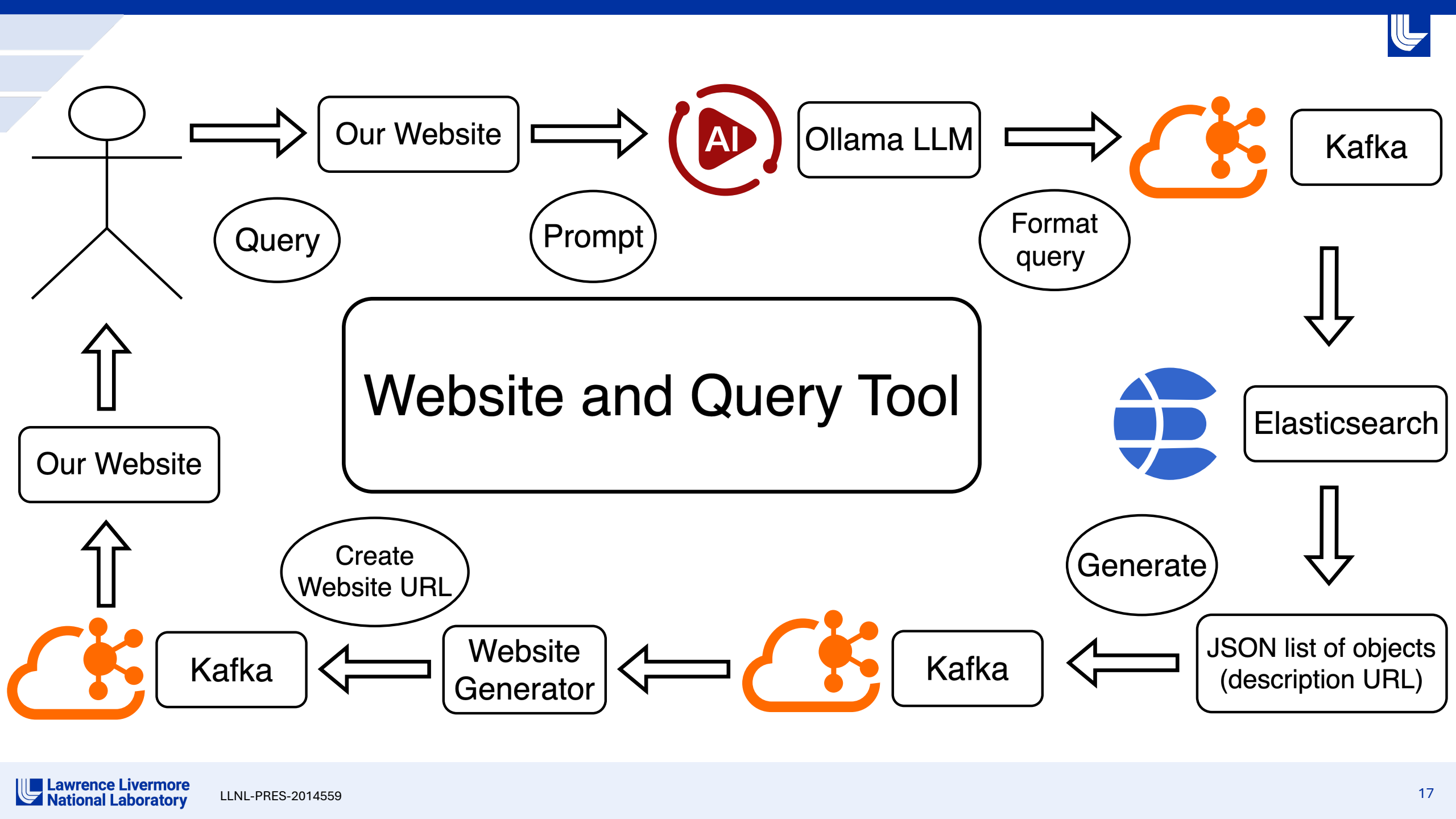
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Demo

Image Generation Pipeline

Step 1 Create Image:

- We pull an image from Unsplash
- Put it in Storagegrid (S3)
- Storagegrid sends out a Kafka Notification

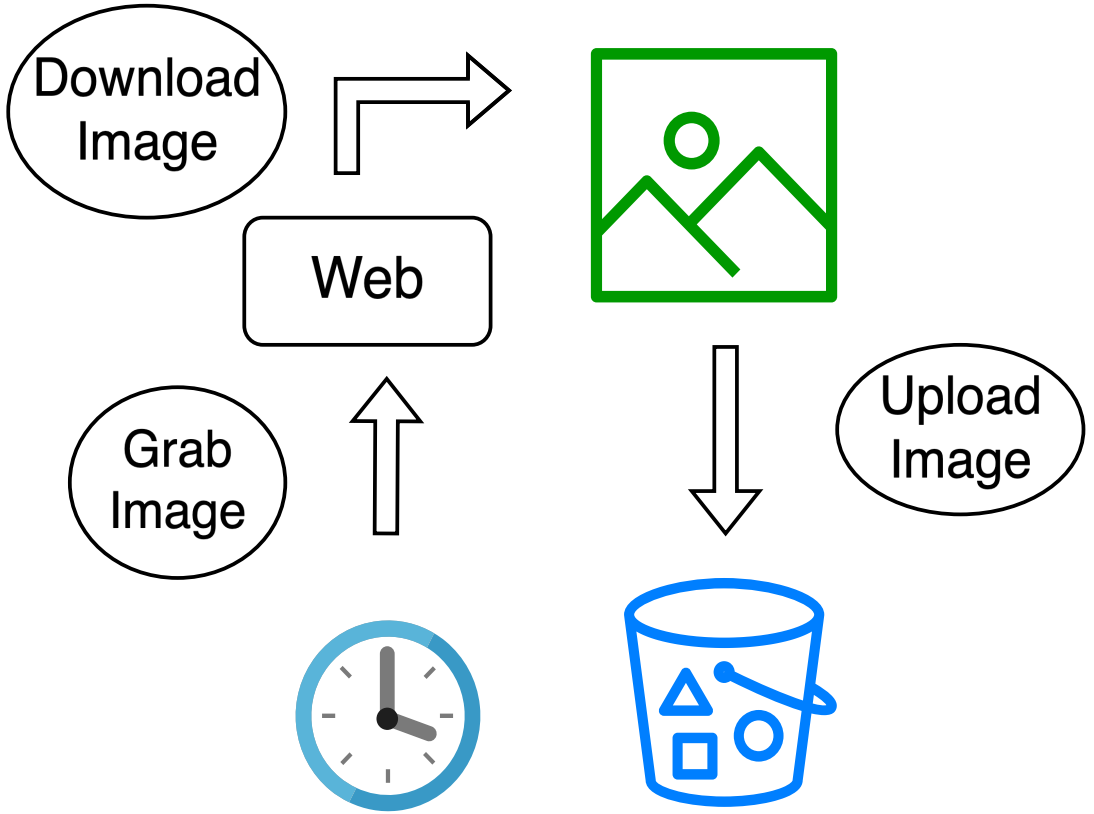


Image Generation Pipeline

Step 2 Notify Analyzers:

- Respond to Kafka Notification
- Notify Analyzer via Kafka and provide the URL to the image in Storagegrid

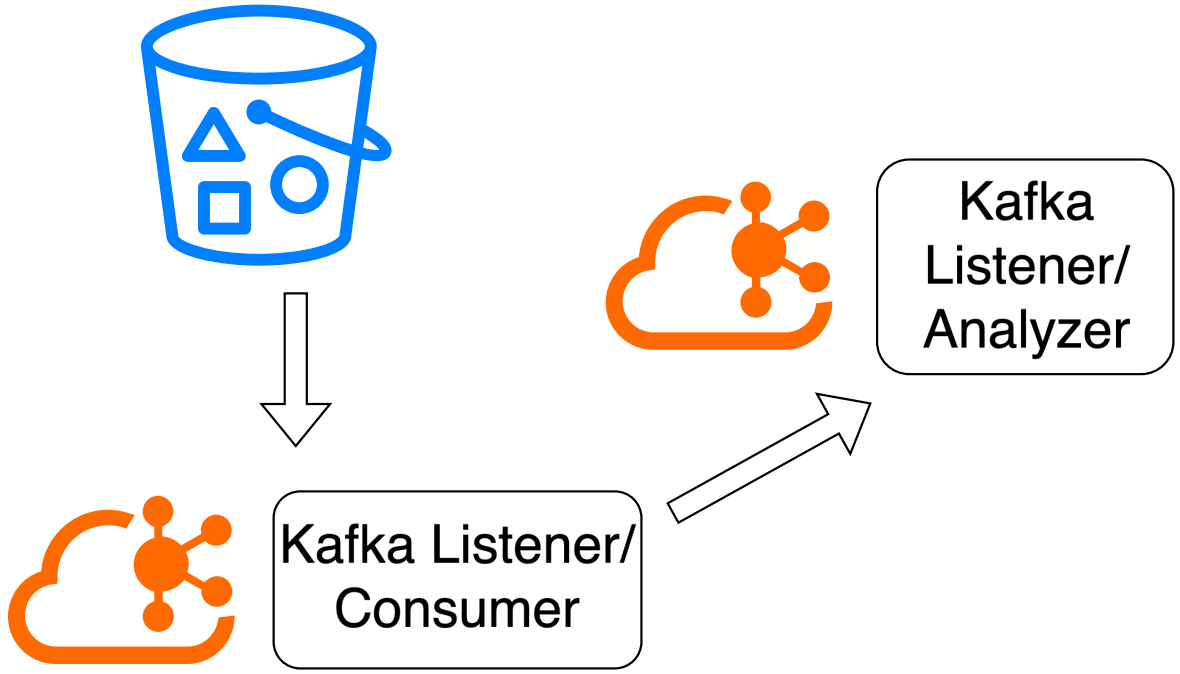


Image Generation Pipeline

Step 3 Analyze Image:

- Respond to Kafka Notification
- Download image
- Prompt LLM via Ollama for Natural Language Description
- Prompt LLM again with NL Desc to get Keyword Desc
- Put URL, NL Desc, and Keyword Desc in Elasticsearch

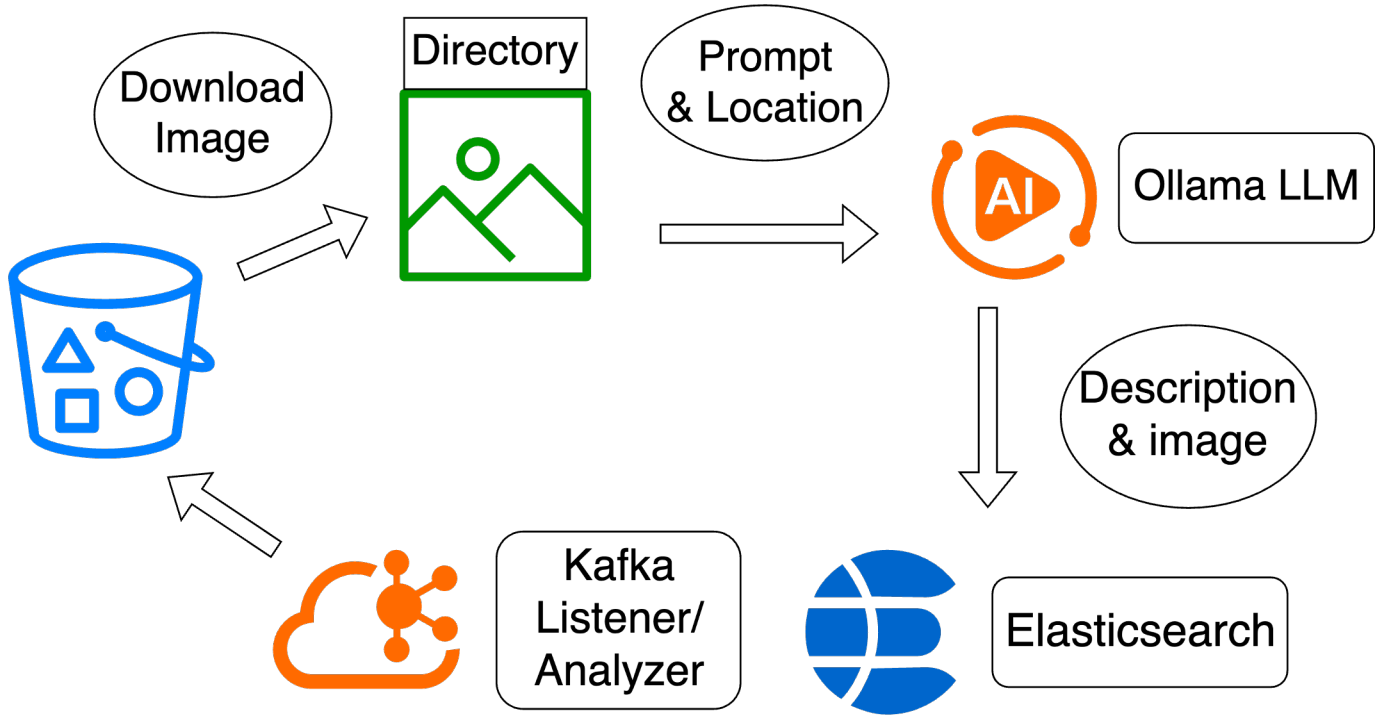


Image Query Pipeline

Step 1 User Website:

- User uses a (somewhat) natural language query
- Backend uses Ollama to turn query into keywords
- Posts both query and keywords to Kafka for Query Tool

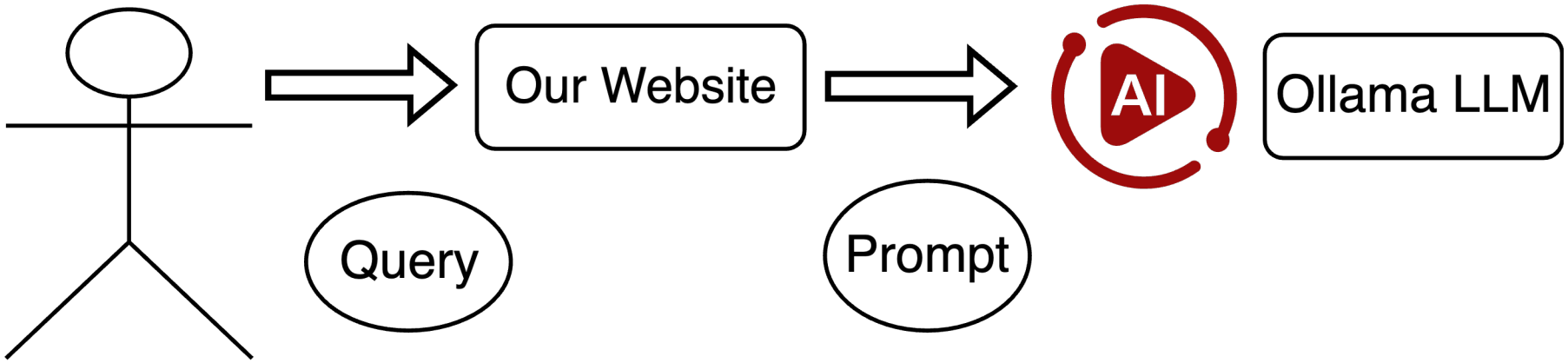


Image Query Pipeline

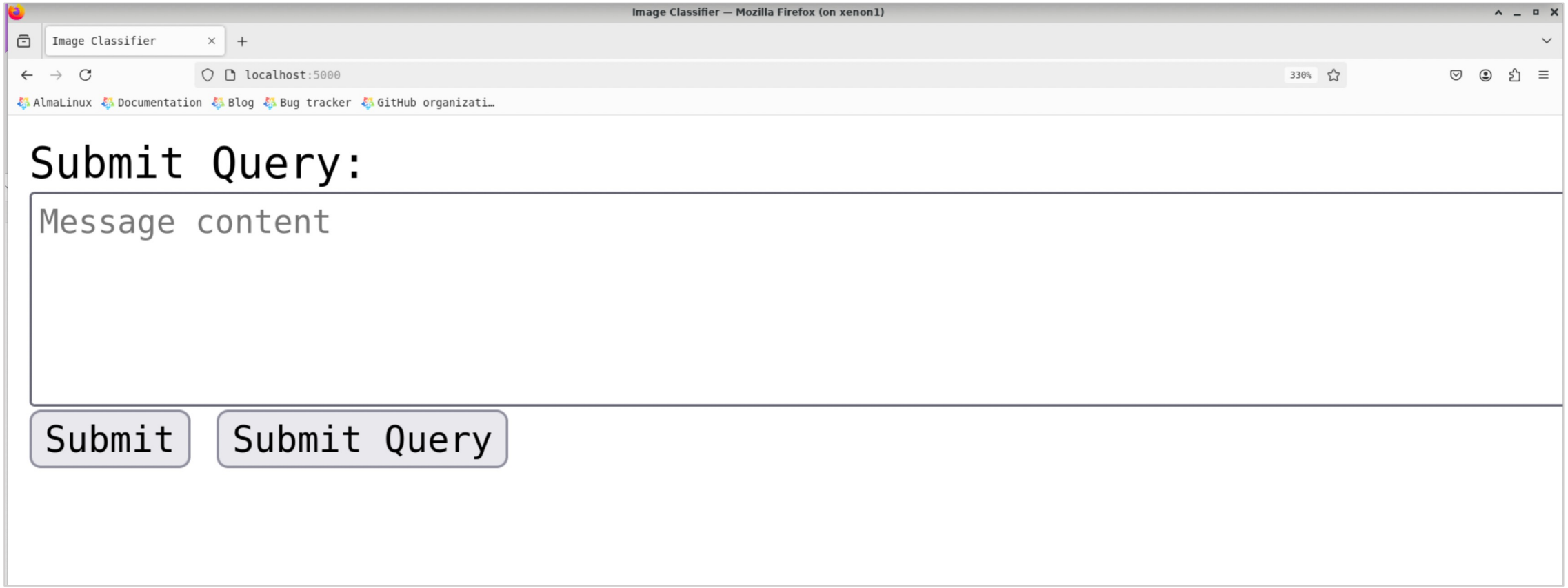


Image Query Pipeline

Step 2 Query Tool:

- Responds to Kafka Message
- Uses Keywords to find images that match all keywords in Elasticsearch
- Posts results and the query to Webpage Generator

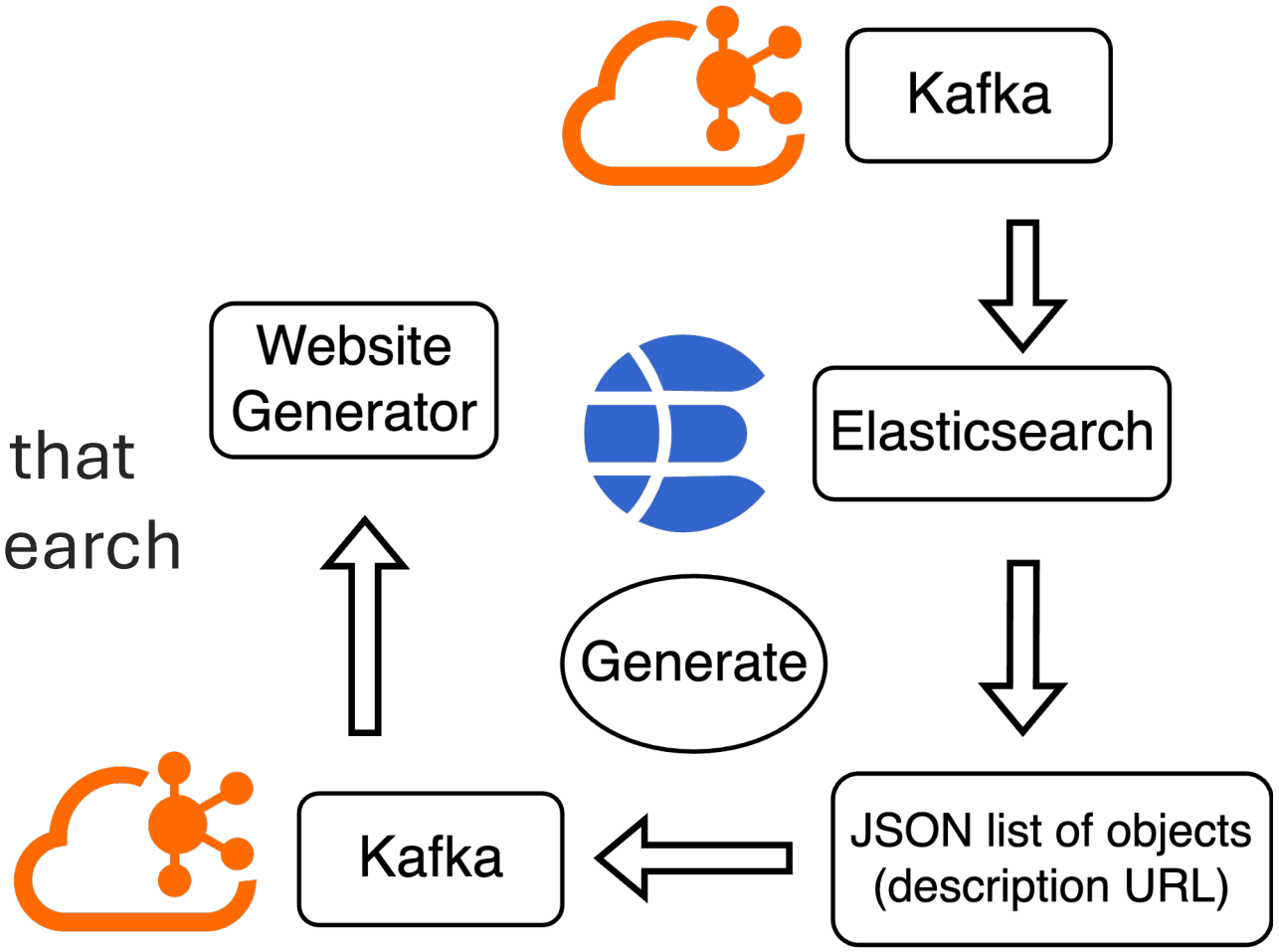


Image Query Pipeline

Step 3 Webpage Generator:

- Responds to Kafka Message
- Builds a static webpage to show the results of the user's query
- Posts a message back to website with the URL of the newly generated webpage

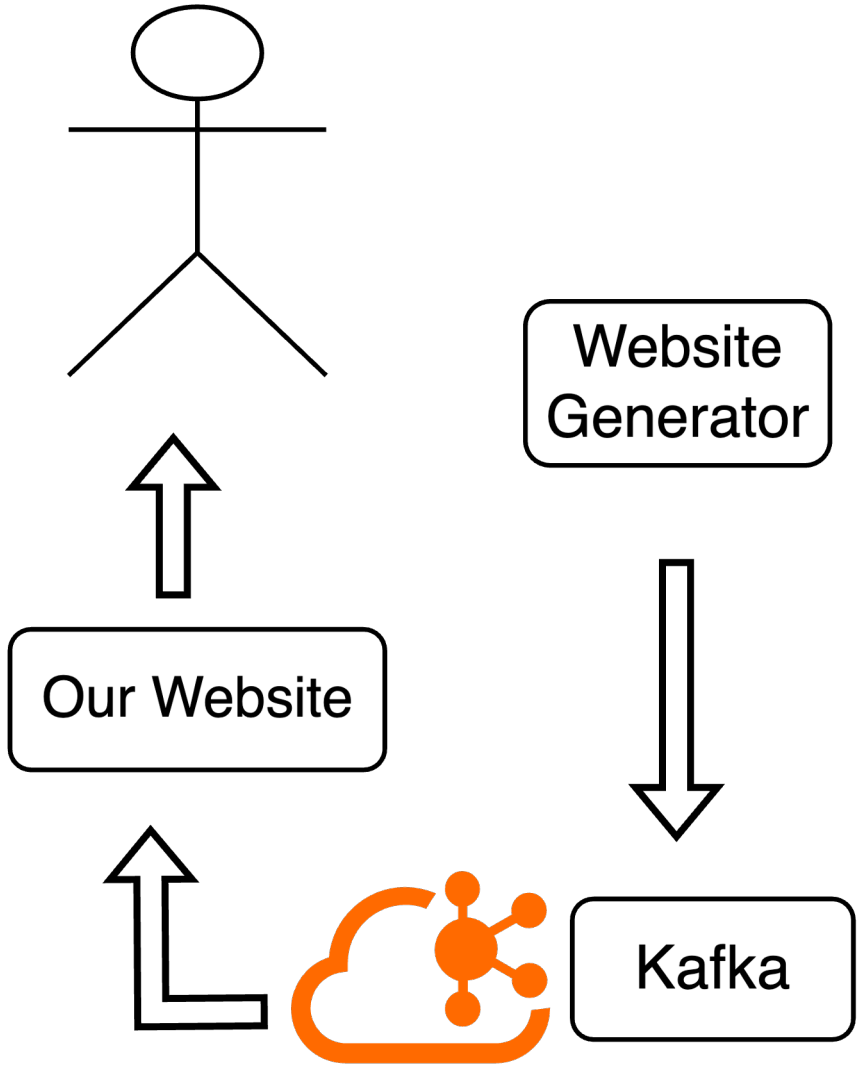
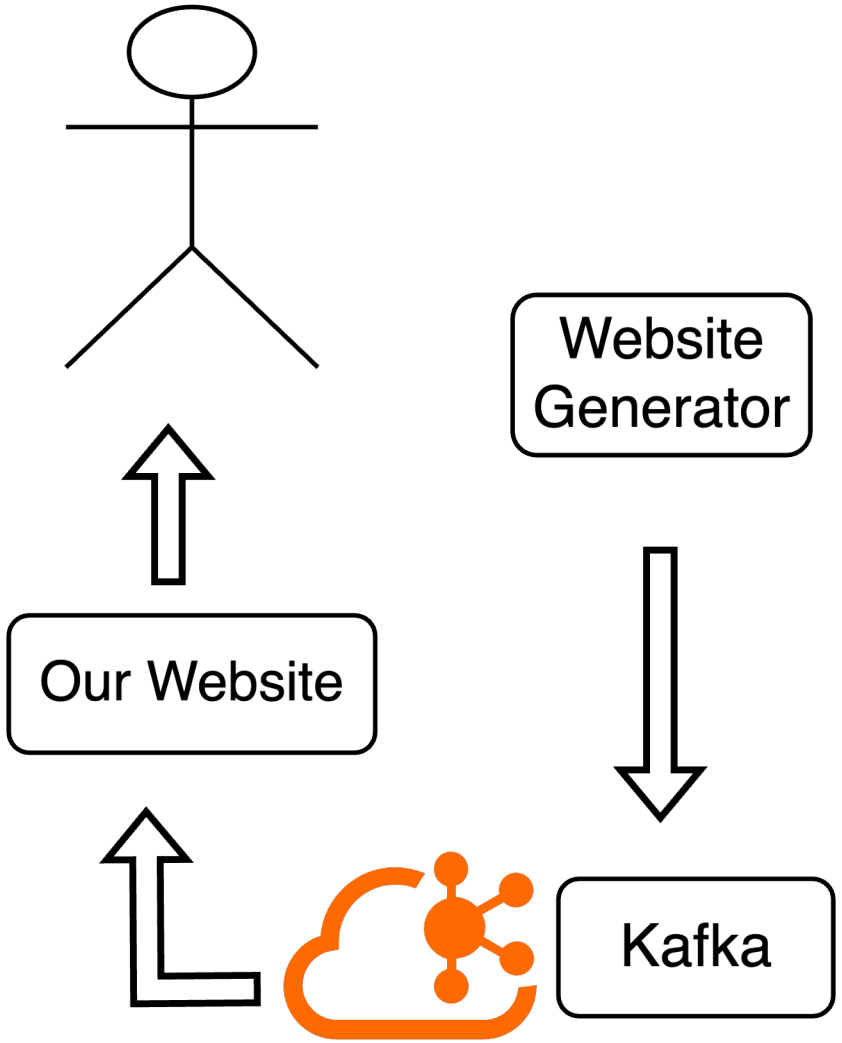


Image Query Pipeline

Step 4 Redirect User:

- Responds to Kafka Message
- Redirect user to newly created webpage to show the results.



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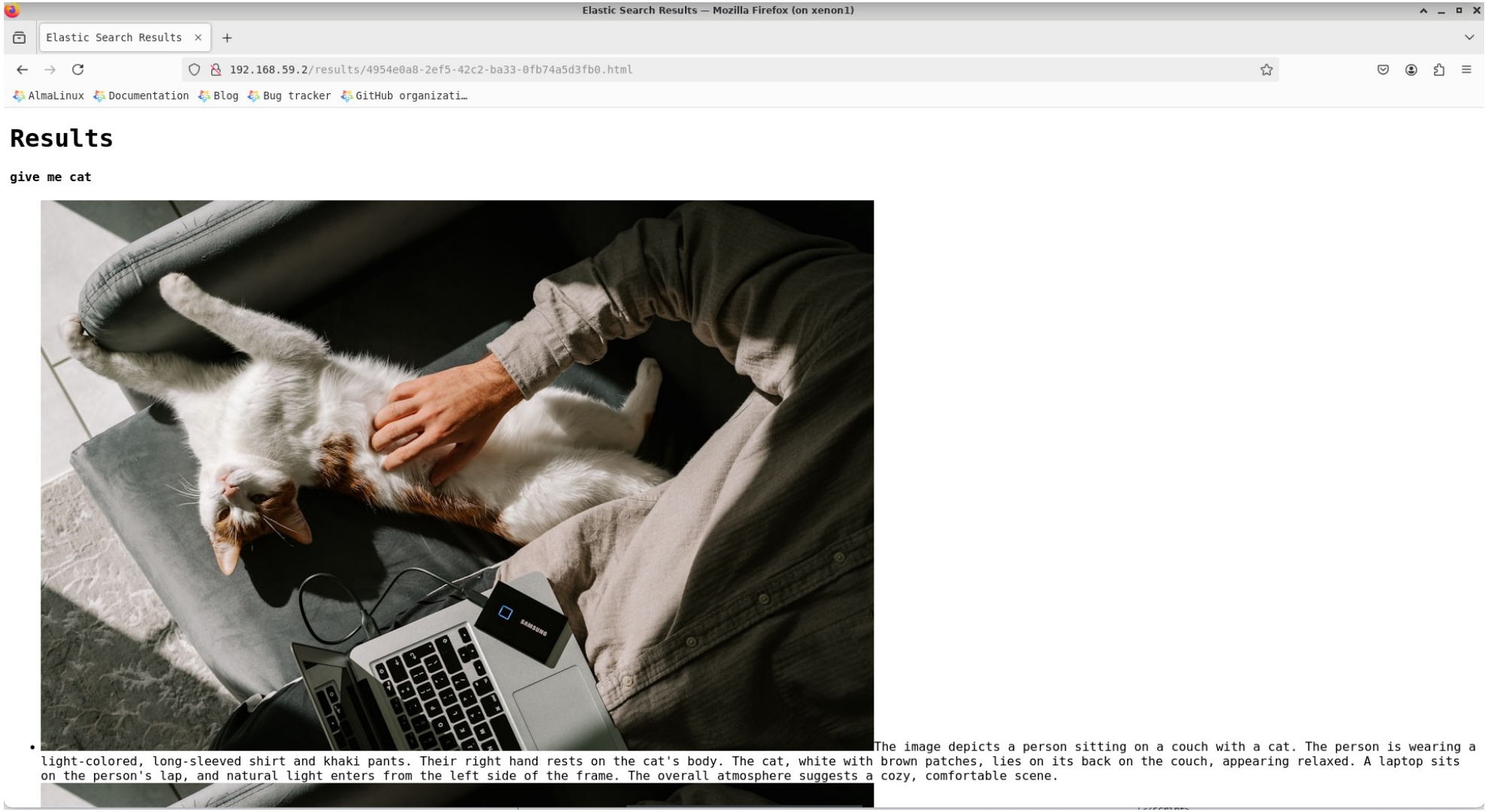

Automation…because running 6 python scripts by hand every time is a pain!

- Ansible playbook deployment
- Systemd services
- Centralized config files

Challenges

- Learning and using the required technologies
  - Containerizing Kafka
  - Configuring StorageGrid bucket for URL access
- Connecting each step of the pipelined workflow
  - Standardizing input and output
- Engineering LLM prompts

Next Steps

- Fine tune the LLM prompts
- Adjust our tool for lab settings
  - Connect image generation to actual lab equipment
  - Train an LLM on lab pictures
- Test the accuracy and speed of search results with a large sample of pictures

Thank you!

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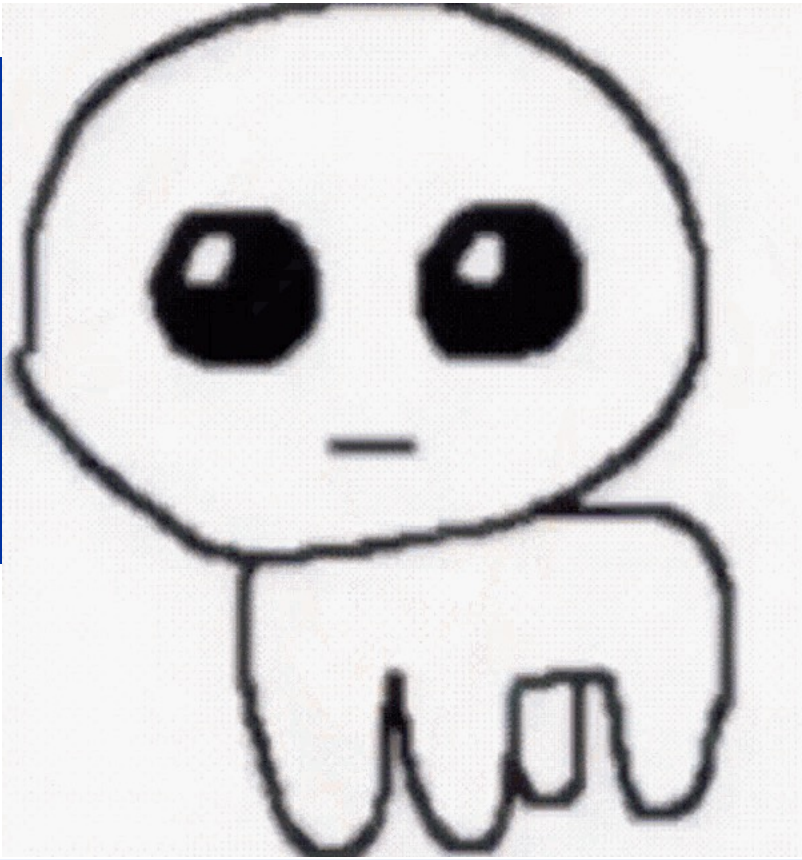

Thank you to our mentors!

Dave Fox

Gabe Maxfield

References

- https://kafka.apache.org/
- https://www.elastic.co/elasticsearch
- https://www.netapp.com/storagegrid/
- https://unsplash.com/
- https://www.freepik.com/
- https://stock.adobe.com/images/
- https://pixabay.com/photos/search/

OpenCHAMI

Open Composable Heterogeneous Adaptable Management Interface

Jasmine Chao and Matthew Torno

Prepared by LLNL under Contract DE-AC52-07NA27344.

Jasmine Chao

Carnegie Mellon University
Electrical and Computer Engineering

Matthew Torno

University of San Diego
Computer Science / Cybersecurity

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What is OpenCHAMI?

> “OpenCHAMI … is an open-source system management platform designed to bring *cloud-like flexibility and security* to HPC environments.

(from the OpenCHAMI official website at https://openchami.org/)

Features

- Makes resource provisioning **simple and modular**
  - Images can be built in any way using a **layer system**
  - Once the images are built, they can be booted any number of times in about a minute
- Features **automated authentication**
  - Integrated cloud-init
  - Manages SSH access, boot parameters and more

Note: OpenCHAMI doesn't include the tools to build, store, and serve system images

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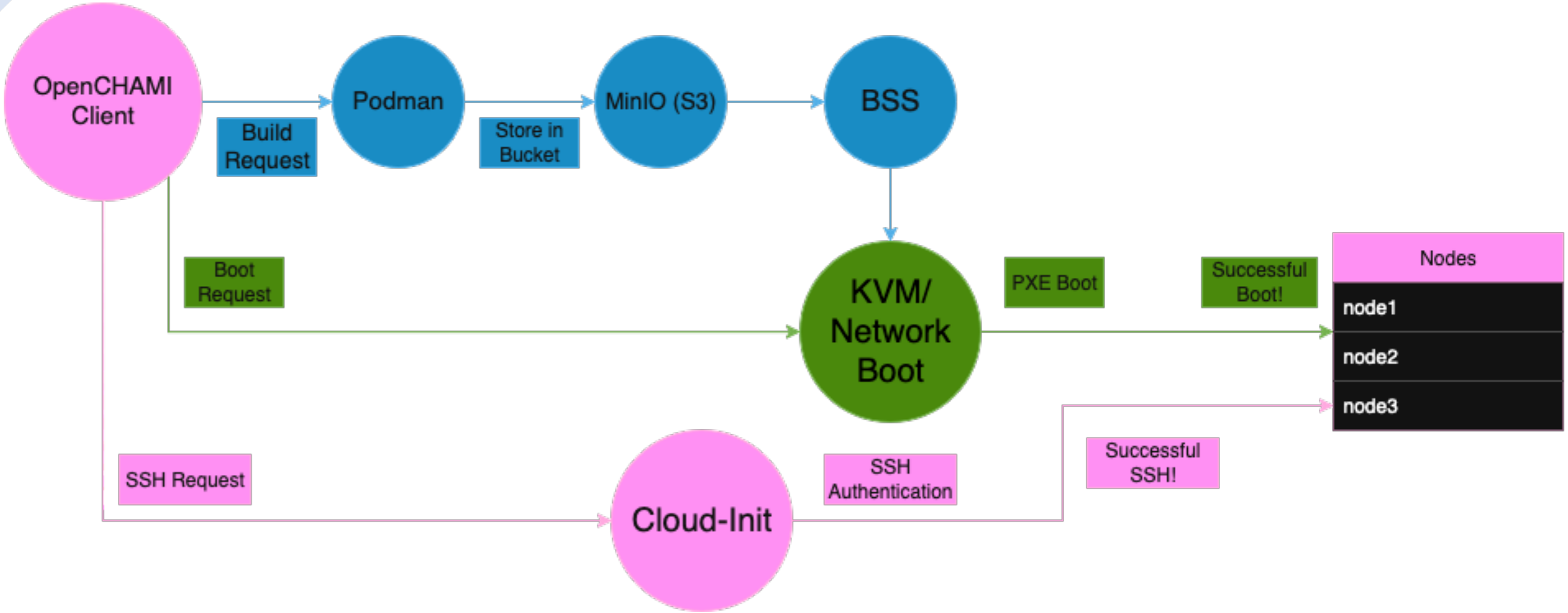

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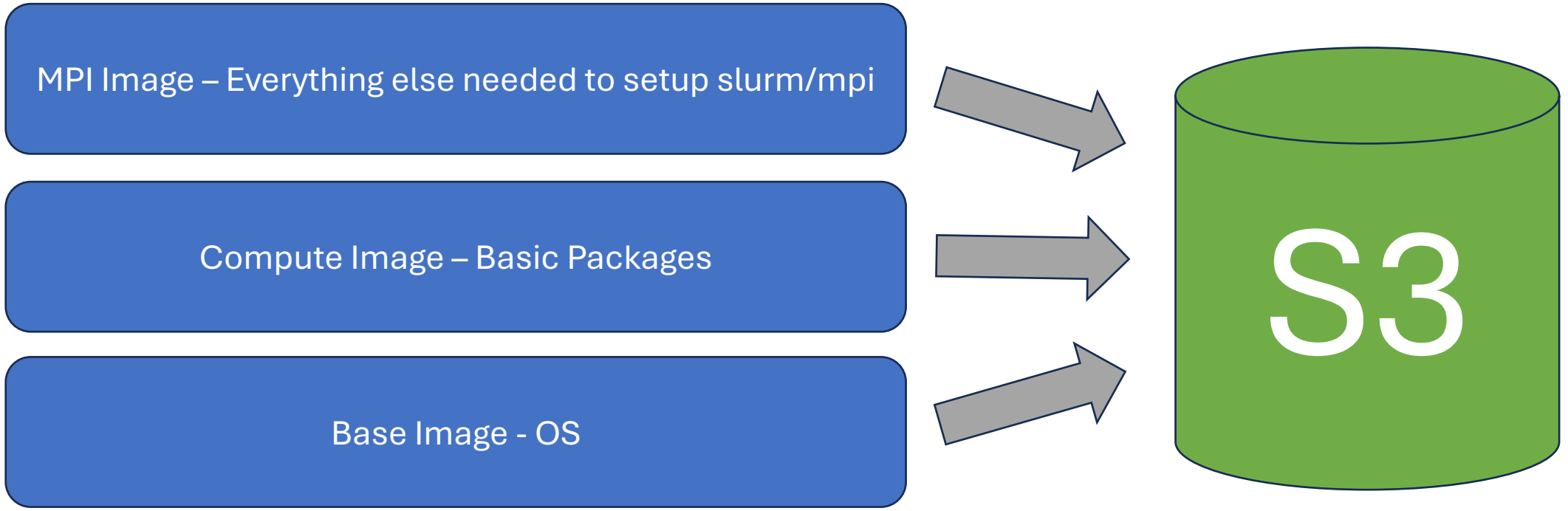
OpenCHAMI Setup- Image Building & Storage



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OpenCHAMI Commands We Used

Configuring the cluster's Virtual Network:

```
ig cluster set --system --default demo cluster.uri https://demo.openchami.cluster:8443
```

Populating SMD (State Management Daemon) with node data:

```
scover static -f yaml -d @/opt/workdir/nodes/nodes.yaml
```

Setting the BSS (Boot Script Service) for PXE:

```
ochami bss boot params set -f yaml -d @/opt/workdir/boot/boot-compute-debug.yaml
```

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Booting from OpenCHAMI is as easy as:

```
[testuser@node1 ~]$ sudo virt-install \
  --name compute1 \
  --memory 4096 \
  --vcpus 1 \
  --disk none \
  --pxe \
  --os-variant centos-stream9 \
  --network network=openchami-net,model=virtio,mac=52:54:00:be:ef:01 \
  --graphics none \
  --console pty,target_type=serial \
  --boot network,hd \
  --boot loader=/usr/share/OVMF/OVMF_CODE.secboot.fd,loader.readonly=yes,loader.type=pflash,nvram.template=/usr/share/OVMF/OVMF_VARS.fd,loader_secure=no \
  --virt-type kvm
```

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So why use OpenCHAMI?

- **Cloud-like infrastructure**
  - HPC systems are rigid and require the customer to work around existing infrastructure
  - OpenCHAMI allows you to **use the resources of HPC** while allowing the **environment portability of cloud.**
  - Can be run on-prem; more control over secrets, systems kept **first-party**
- **Scientific application**
  - HPC changes constantly but OpenCHAMI can **provision older or specific environments** to recreate experiments

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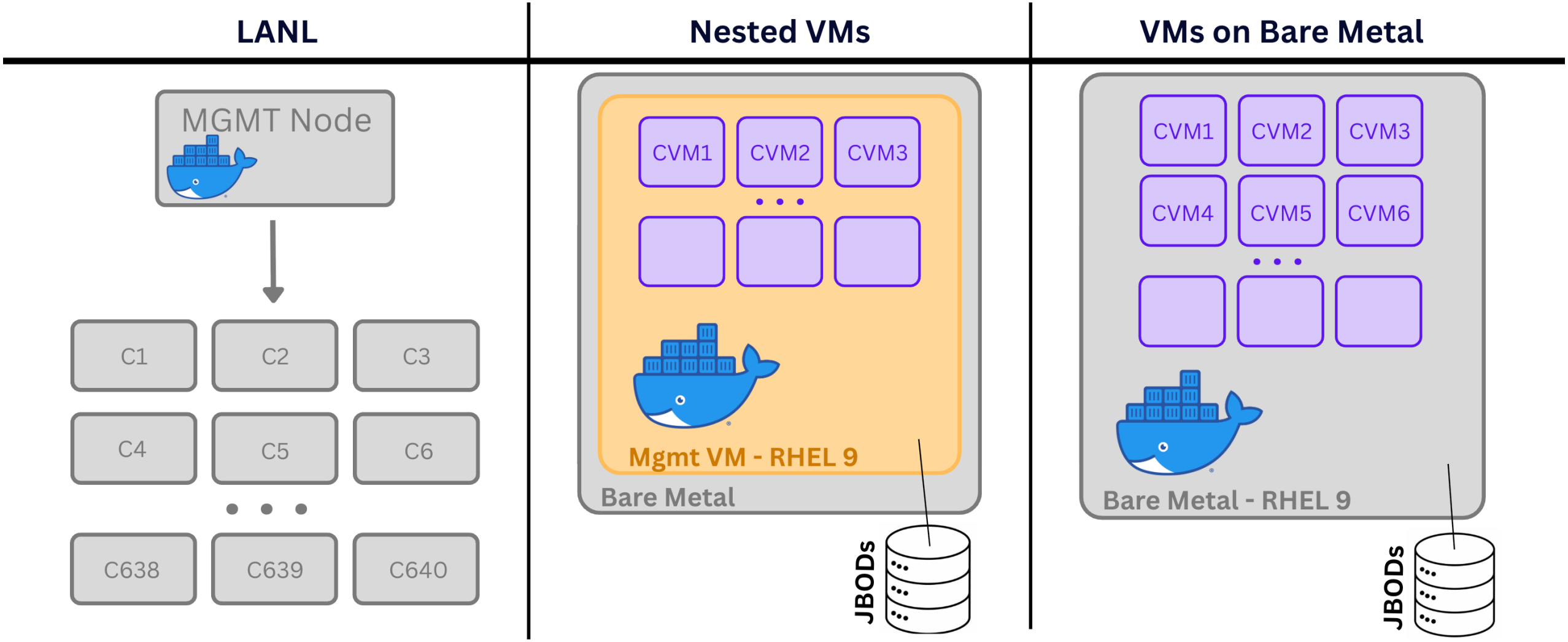
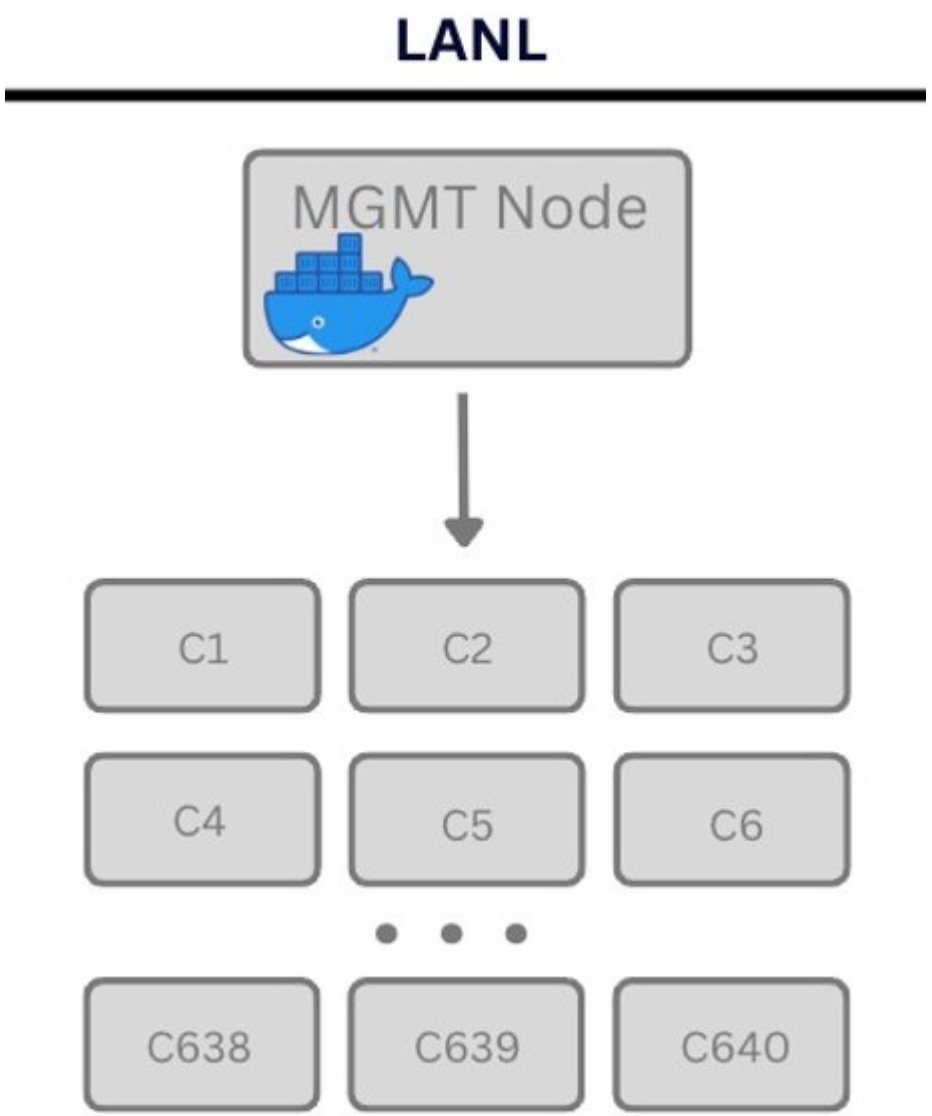
Models Explored



LANL Model Analysis

- Similar to **current HPC model**
  - Single management node provisions a large amount of **physical** compute nodes



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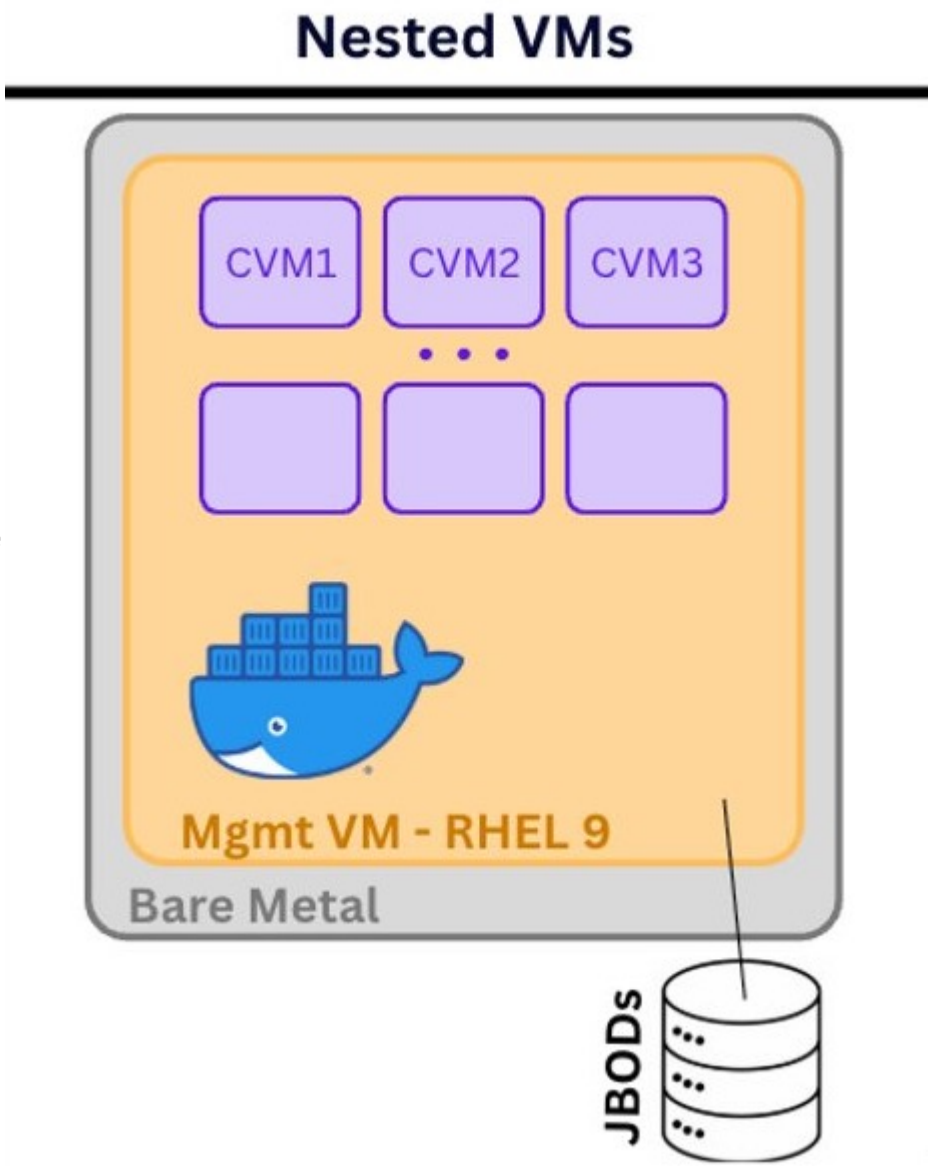
Nested VMs/Cloud Model Summary

- **Advantages**:
  - Allows for **cloud-like flexibility**
  - Resource provisioning **like cloud**
  - VM parameters can be **controlled to simulate specific environments**
- **Disadvantages**:
  - Worse runtime performance
  - Larger overhead
  - Requires more **complex networking setup**
  - Can't scale out



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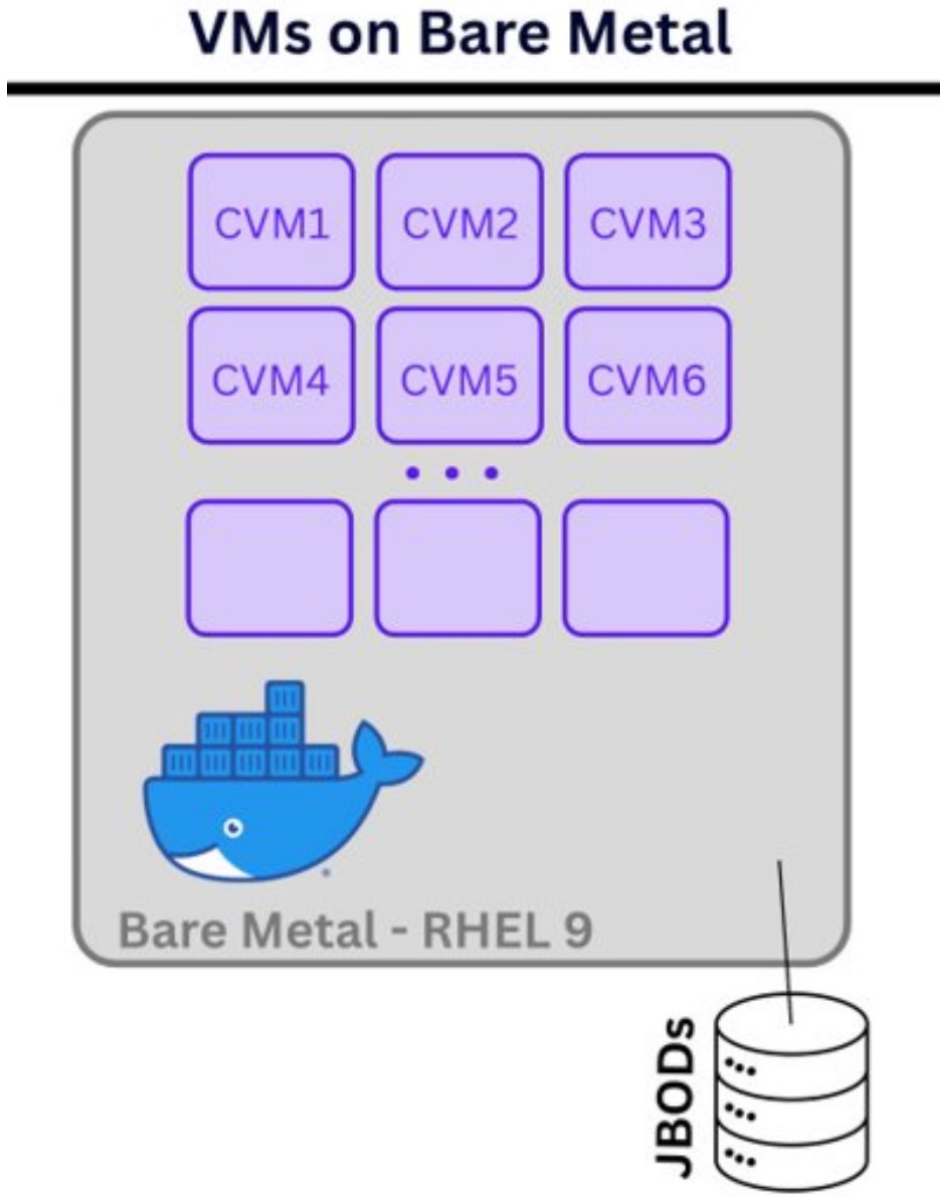
VMs on Bare Metal Model Summary

- **Advantages**:
  - Simpler to provision and network
  - No nested virtualization needed (performance boost)
  - Can scale out
- **Disadvantages**:
  - Less flexible than VM environment
  - Harder to clean and reset



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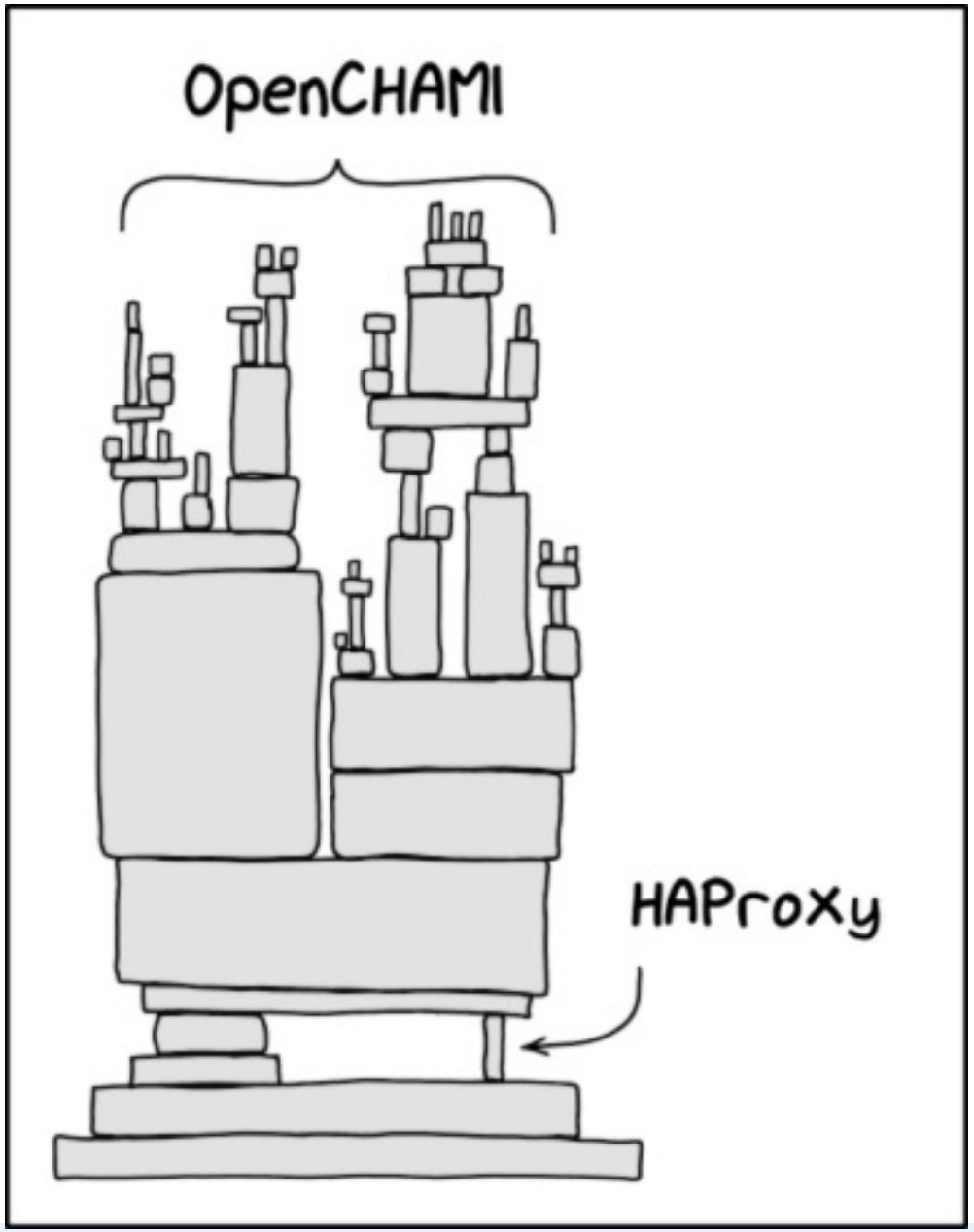

(From XKCD)

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Challenges

Setting up OpenCHAMI	Using OpenCHAMI
RHEL 8 on host not supported	JWTs (JSON Web Tokens) have to be **reset every hour**
Image building temporarily **requires a lot of disk space** • The actual images aren't as big	Cloud-init makes SSH **less flexible**
Lot of dependencies that sometimes fail	Booted VMs are **diskless** and have **low storage** (~700MB)
Continuous updates to OpenCHAMI	

Next Steps

Sysadmins	Customers
Test and directly implement **LANL's** OpenCHAMI setup	**Scale out** to support more remote connections
Install and set up **FLUX**	Integrate **S3 buckets** for the provisioned nodes
Set up **High Speed Interface** (HSI)	
Setup on **TOSS 5**	

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```
[testuser@nickel6 ~]$ sudo virt-install \
  --name compute1 \
  --memory 4096 \
  --vcpus 1 \
  --disk none \
  --pxe \
  --os-variant centos-stream9 \
  --network network=openchami-net,model=virtio,mac=52:54:00:be:ef:01 \
  --graphics none \
  --console pty,target_type=serial \
  --boot network,hd \
  --boot loader=/usr/share/OVMF/OVMF_CODE.secboot.fd,loader.readonly=yes,loader.type=pflash,nvram.template=/usr/share/OVMF/OVMF_VARS.fd,loader_secure=no \
  --virt-type kvm
```

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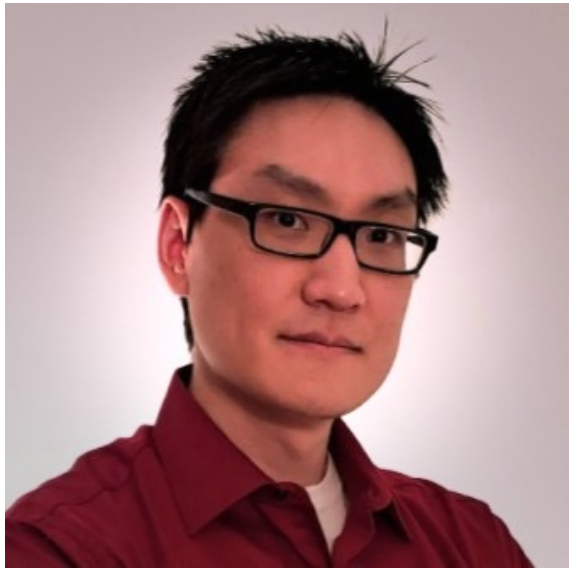

Jason Kim

Naomi Cheeves

Martin Baltezore

Also, thanks to Dave Fox and Gabe Maxfield

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Sources

- https://www.openchami.org/
- https://github.com/OpenCHAMI/tutorial-2025/tree/main

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