National Science Foundation's Industry/University Cooperative Research (I/UCRC) Program

# F2-24: Development of Large AI Applications and Systems

Mission-Critical Computing
NSF CENTER FOR SPACE, HIGH-PERFORMANCE, AND RESILIENT COMPUTING (SHREC)

SHREC Annual Workshop (SAW23-24)

University of Pittsburgh
BYU BRIGHAM YOUNG UNIVERSITY
VIRGINIA TECH
UF UNIVERSITY of FLORIDA

January 17-18, 2024

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Professor of ECE

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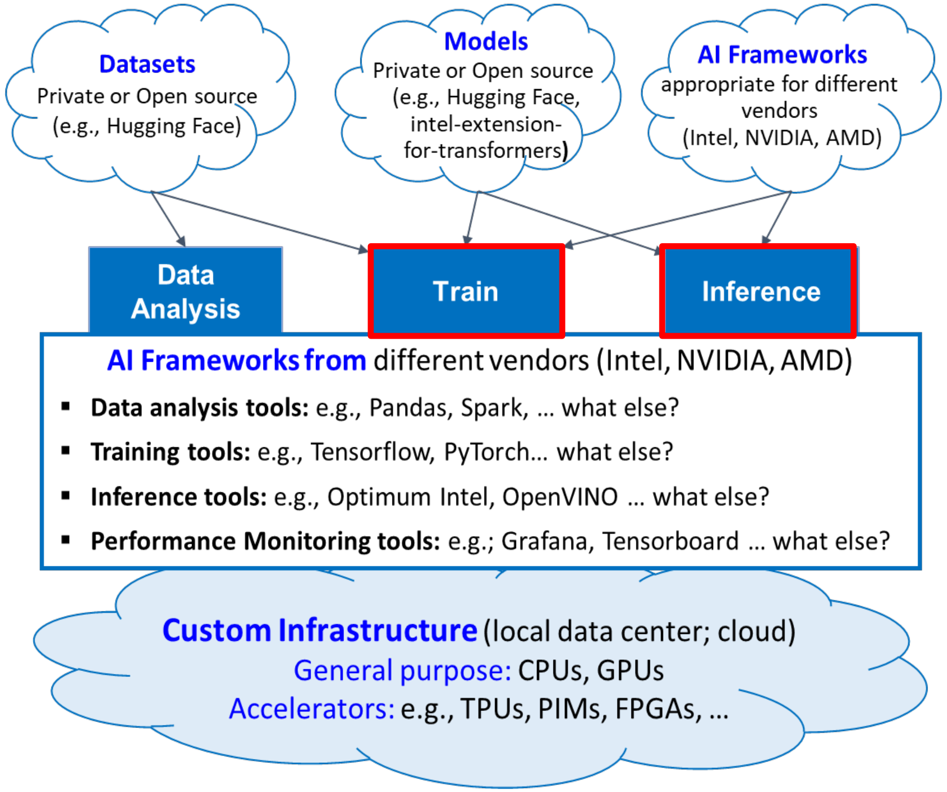
Research Students
University of Florida

Number of requested memberships ≥ 4

# Motivation

- Creating hardware infrastructures for developers faced with a complex array of choices: *dataset*, *model*, AI *framework*, & hardware *infrastructure*



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Private or Open source
(e.g., Hugging Face)

**Models**
Private or Open source
(e.g., Hugging Face, intel-extension-for-transformers)

**AI Frameworks**
appropriate for different vendors
(Intel, NVIDIA, AMD)

Data Analysis

Train

Inference

**AI Frameworks from** different vendors (Intel, NVIDIA, AMD)

- **Data analysis tools:** e.g., Pandas, Spark, … what else?
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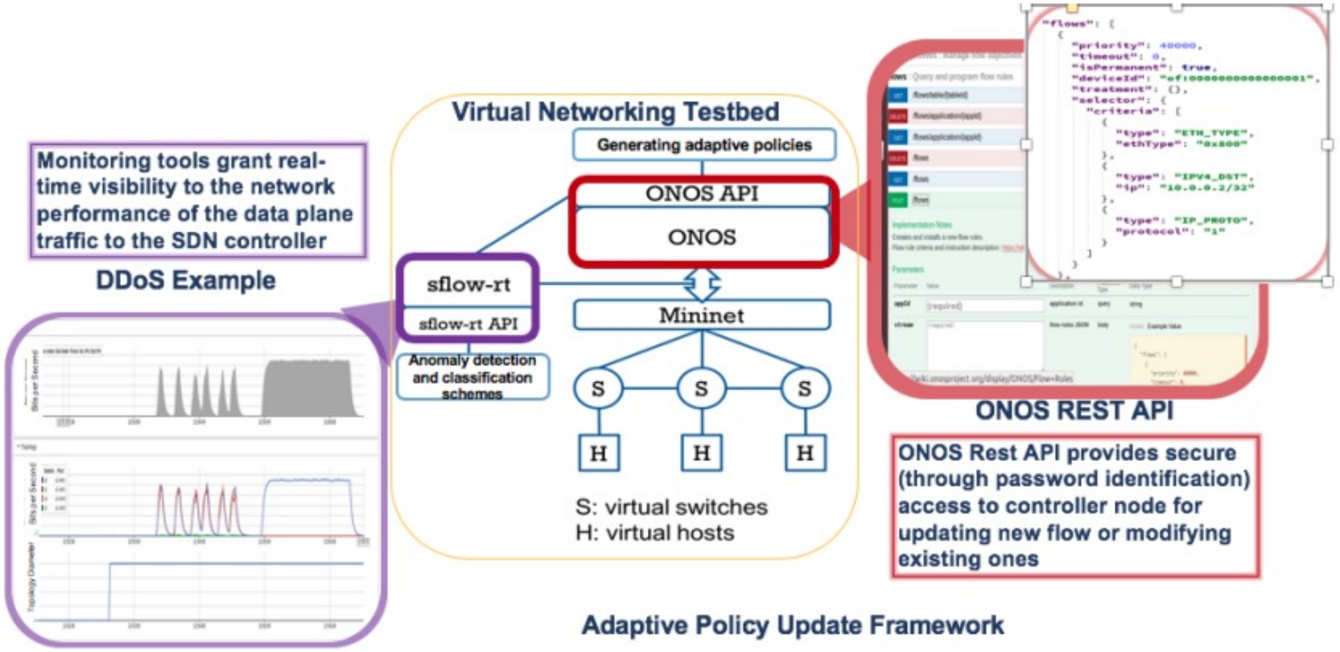
**Custom Infrastructure** (local data center; cloud)
General purpose: CPUs, GPUs
Accelerators: e.g., TPUs, PIMs, FPGAs, …



Monitoring tools grant real-time visibility to the network performance of the data plane traffic to the SDN controller

DDoS Example

Virtual Networking Testbed

Generating adaptive policies
ONOS API
ONOS
sflow-rt
sflow-rt API
Mininet
Anomaly detection and classification schemes
S
S
S
H
H
H

S: virtual switches
H: virtual hosts

ONOS REST API

```
"flows": [
  {
    "priority": 40000,
    "timeout": 0,
    "isPermanent": true,
    "deviceId": "of:0000000000000001",
    "treatment": {},
    "selector": {
      "criteria": [
        {
          "type": "ETH_TYPE",
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    }
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ONOS Rest API provides secure (through password identification) access to controller node for updating new flow or modifying existing ones

Adaptive Policy Update Framework

- Creating network architectures for applications, *such as security and quality of service,* that can generate and leverage *real-time situational awareness* through new network profile *data sets*, network *models*, and *machine learning and AI-based* protocols.

# Project Goal & Approach

**Goal**

***Optimize and advance*** key technologies that will accelerate performance of *mission-critical* systems

- *Software-based network management* for mission-critical deployments
- *Routing performance and adaptive parameters* for 5G satellite communications
- *Enhance AI integrAItor FY-2023* & focus on a *new generation of LLMs*[1]

## R&D Approach and F2 Projects

- **T1:** Develop *RAvN*[1] for adaptive and responsive SDN[2]-manages tactical network resilience
- **T2:** Develop *reinforcement learning techniques* for satellite topology reconfiguration.
- **T3:** Enhancements to *integrAItor* FY-2023
- **T4:** Focus on integration support of *federated learning,* using *domain-specific* LLM[3] and *RAG*[4]*/RCG*[5] generation of LLM[3]
  - **T4a:** *Fine-tuning* of *pre-trained* models (not training from scratch)
  - **T4b:** *RAG*[4]*/RCG*[5] generation for Large Language Models

[1] RAvN: Responsive auto-nomic and data-driven adaptive virtual networking framework

[2] SDN: Software-defined networks

[3] LLMs: Large Language Models

[4] RAG: Retrieval-Augmented Generation

[5] RCG: Retrieval-Centric Generation

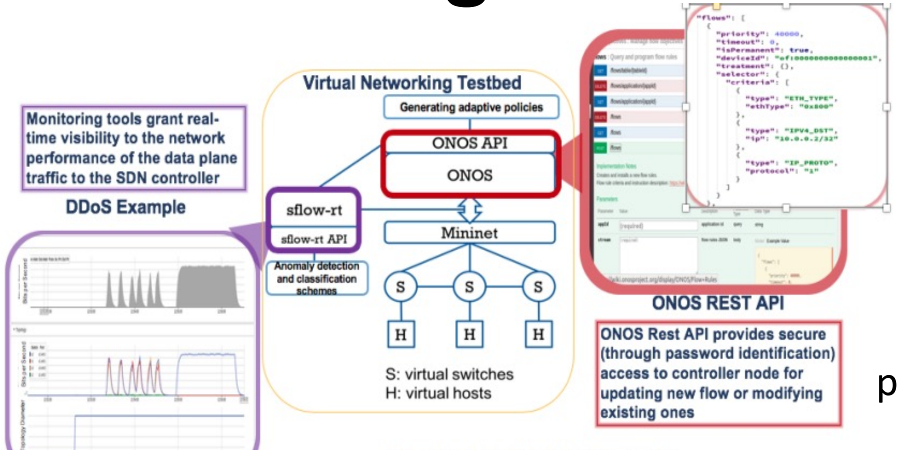
F2

# T1: RAvN[1] for SDN[2]-managed tactical network resilience

## Research Thrust 1

### Machine-Learning Approach

Determine tactical network status by analyzing a library of  observed network metrics.



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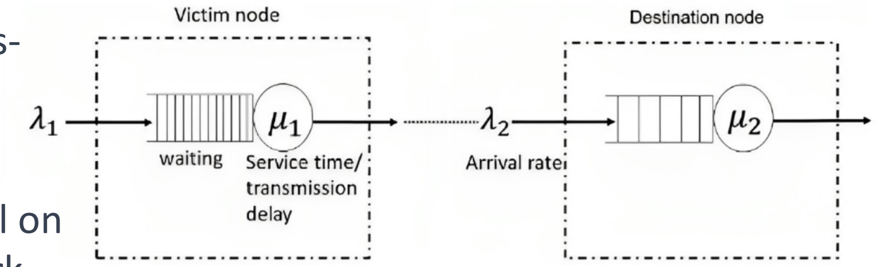
Adaptive Policy Update Framework

- **Data Generation:** Generate data and network samples utilizing SimComponents a network traffic simulation software developed based on the SimPY process-based discrete event simulation framework.
- **Training**: Train machine learning model on non-attack (normal) and attack network samples.
- **Analysis:** Detect, identify, and mitigate cyberattacks within a tactical network.



## Research Thrust 2

### SDN Controller Architecture

Only fine-tune a small number of (extra) model parameters while freezing most parameters of model

- **Architecture:** Comparison of decentralized, distributed, redundant, and hierarchical controllers.
- **Metrics**: Collect interarrival times, transmission delay, and packet counts received at a servers and controllers.
- **Actuation:** Metrics can be captured by the forwarding nodes and subsequently transmitted to the controller for onward transmission to the network operator. Isolate and redirect network traffic away from a compromised node.
- **Analysis:** Mininet network emulation analysis.

[1] RAvN: Responsive auto-nomic and data-driven adaptive virtual networking framework

[2] SDN: Software-defined networks

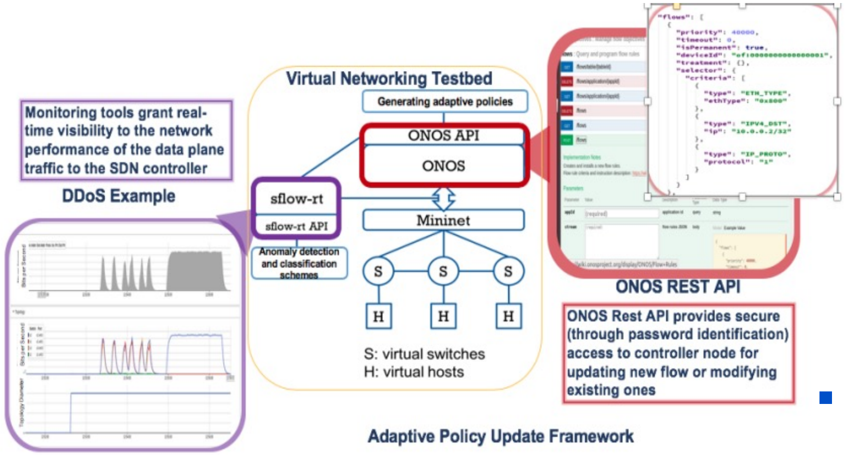
# T2: *Reinforcement learning techniques* for satellite topology reconfiguration.

## Research Thrust 1

### Machine-Learning Approaches

Explores the application of a shortest-distance reconfiguration algorithm in satellite constellations.

- **Shortest Distance Algorithm:** Address the performance disparity according to the size of the satellite constellations.
- **Training**: Train machine learning model on failure conditions, including device, link and signal failures.
- **Analysis:** Investigate using reinforcement learning or some other machine learning approach for satellite topology reconfiguration for various constellation sizes.



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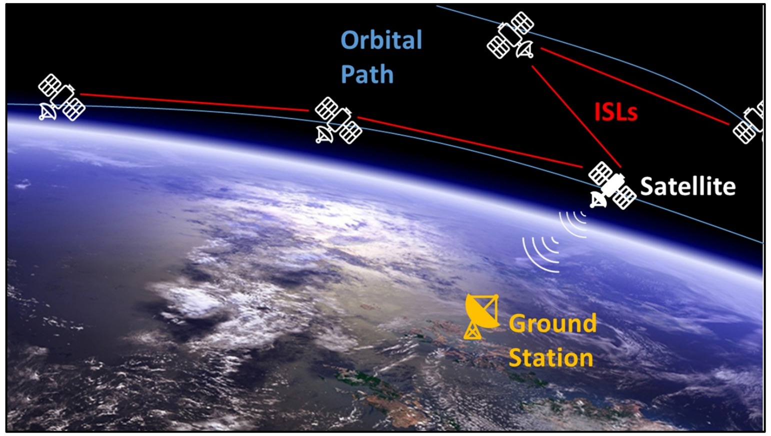
Adaptive Policy Update Framework



## Research Thrust 2

### Satellite Network Performance Analysis

Examine new tools for more accurate performance evaluation

- **SDN-based Approach:** Using SDN controllers to manage satellite topology.
- **Quantum Satellite Networks:** Begin an investigation of quantum networking for satellites
- **Topology:** Access to systems tool kit (formerly satellite tool kit for topology generation with connectivity data.
- **Metrics**: Collect connection times, duration, delay, transition time, from orbital dynamics.
- **Integrated Analysis:** Integrate STK output data with a network simulator, e.g., satellite network simulator 3, omnet++, or Mininet.

[1] RAG: Retrieval-Augmented Generation

[2] RCG: Retrieval-Centric Generation

F2

# T3: Enhancements to *integrAItor* FY-2023

## Research Thrust 1

### onDemand Developer Mode

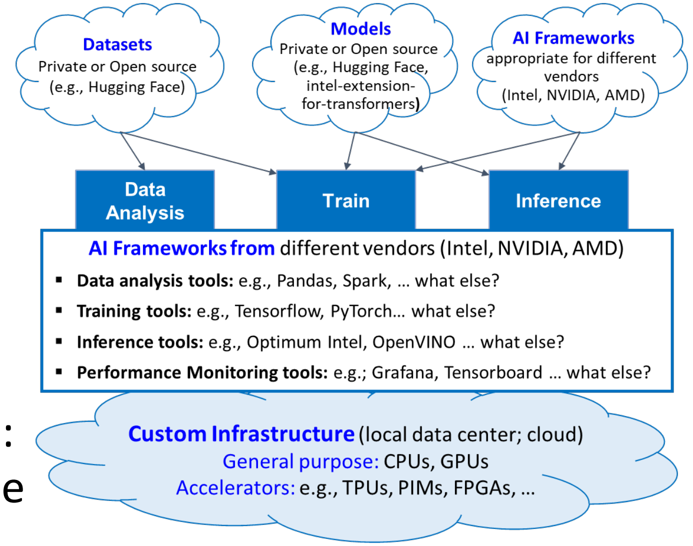
Interactive ***Jupyter Notebook*** environ. for *flexible* development, experimentation, & evaluation

A "***playground"*** that supports developers:

- to customize *existing* or write *new* code
- to flexibility explore, monitor, analyze, and optimize AI applications

Harness ***OnDemand*,***

- *an Open-source web portal* to access computer systems through the web
- enables computation from anywhere, on any device



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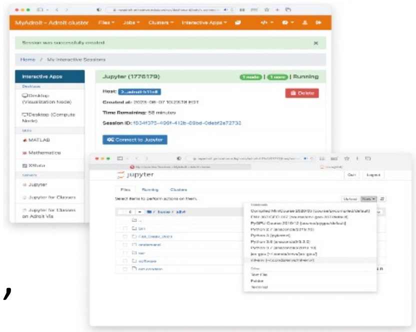


## Research Thrust 2

### Flexible Experiment Tracking & Monitoring

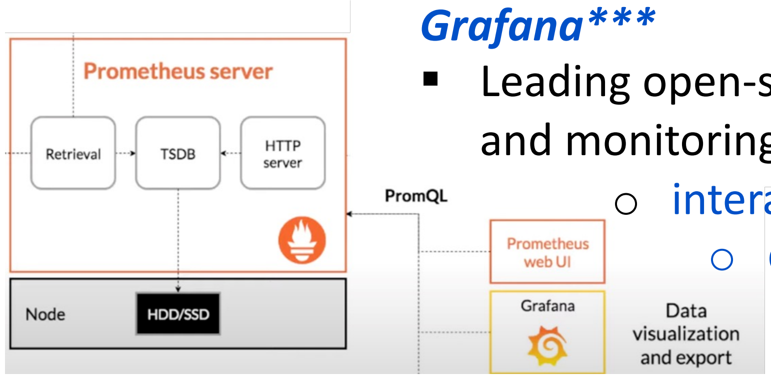
Extensive collection/presentation of evaluation metrics using ***Prometheus***** and ***Grafana******

***Prometheus*****

- Monitor/track metrics from servers, network, and applications to provide real-time insights

***Grafana******

- Leading open-source data visualization and monitoring platform:
  - interactive dashboards
  - data consolidation
  - highly customizable



* onDemand: https://openondemand.org/

** Prometheus: https://prometheus.io

*** Grafana: https://grafana.com/

# T4a: Fine-tuning of Pre-trained Models

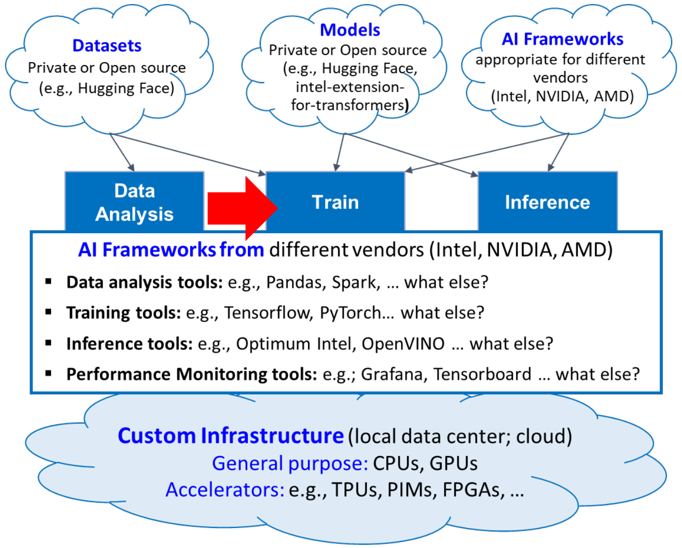
FY-2024 Focus on integration support of *federated learning* using *domain-specific LLM* & *RAG1[1]/RCG[2] generation of LLM*

## Research Thrust 1

**Train Models with *Transfer Learning***

Model trained on one task is adapted and fine-tuned for a different but related task

- **Inter-Task Compatibility:** Explore task compatibility in transfer learning to support selecting the best pre-trained models for given tasks
- **Adaptive Learning Rates**: Provide adaptive visualization tools to support experiments in varying learning rates



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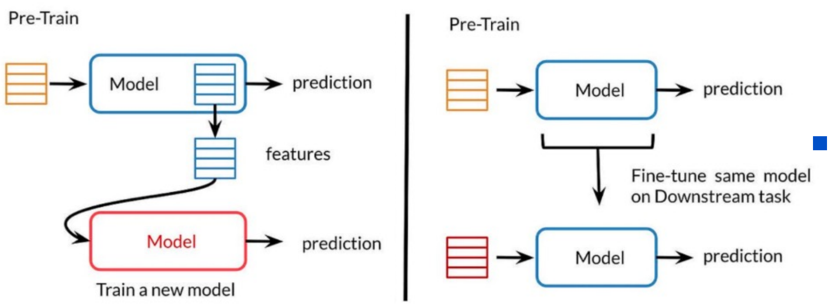

## Research Thrust 2

**Fine-Tuning Model with *PEFT****

Only fine-tune a small number of (extra) model parameters while freezing most parameters of model

- **Incremental Learning** : Integrate existing and emerging libraries/tools for PEFT models to learn new data incrementally while retaining existing knowledge
- **Performance Monitoring:** Set up metrics and monitoring to quickly optimize PEFT

*PEFT: Parameter-Efficient Fine-Tuning

[1] RAG: Retrieval-Augmented Generation
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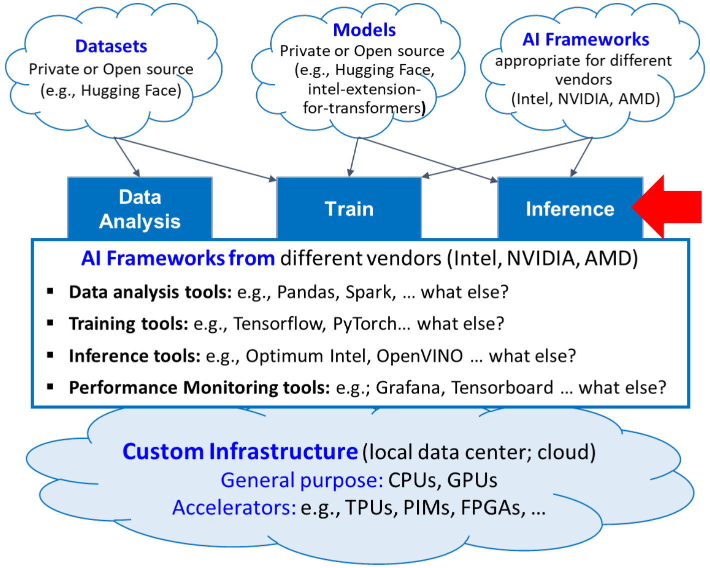
# T4b: RAG and RCG for LLM



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**Research Thrust 1:**

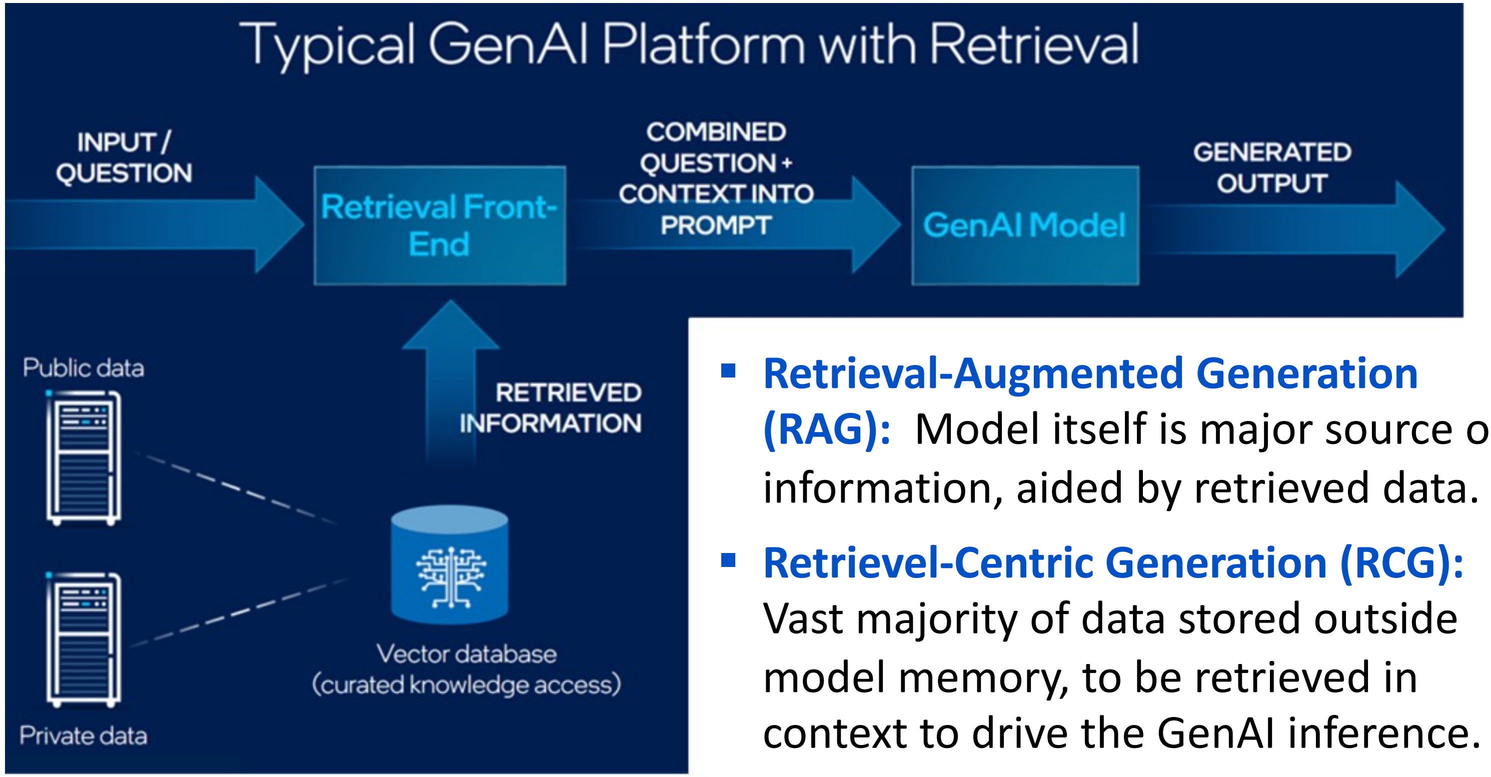
- Explore & determine capabilities of commercial and open-source RAG/RCG tools and libraries (e.g., from Intel, Hugging Face)

**Research Thrust 2:**

- Integrate RAG/RCG tools into *integrAItor*

**FY-2024** Focus on integration support of ***federated learning*** using ***domain-specific LLM*** & ***RAG/RCG generation of LLM***

## T4b: RAG and RCG for LLM*



Typical GenAI Platform with Retrieval
INPUT / QUESTION
Retrieval Front-End
COMBINED QUESTION + CONTEXT INTO PROMPT
GenAI Model
GENERATED OUTPUT
RETRIEVED INFORMATION
Public data
Private data
Vector database (curated knowledge access)

- **Retrieval-Augmented Generation (RAG):** Model itself is major source of information, aided by retrieved data.
- **Retrievel-Centric Generation (RCG):** Vast majority of data stored outside model memory, to be retrieved in context to drive the GenAI inference.

* "GenAI Architecture Shifting from RAG Toward Interpretive Retrieval-Centric Generation (RCG) Models", Gadi Singer, Director of Emergent AI Research at Intel Labs.

# Milestones, Deliverables & Budget

## Milestones

- SMW24: Showcase midway progress on framework, platform, and interconnect exploration
- SAW24-25: Present completed project results

## Deliverables

- Application source code and technology-transfer support
- Progress reports documenting research methods, progress, results, and analysis
- Several conference and/or journal publications

## Membership Budget

- Requesting ≥ 4 memberships

# Conclusions & Member Benefits

## Conclusions

- Creating network architectures for applications, *such as security and quality of service,* that can generate and leverage *real-time situational awareness* through new network profile *data sets*, network *models*, and *machine learning and AI-based* protocols.
- A developer is faced with a complex array of choices: *dataset*, *model*, AI *framework*, & hardware *infrastructure*
  - The goal is to enhance *AI integrAItor* FY-2023 & focus on a new generation of LLMs

## Member Benefits

- Direct influence over selected architecture, app, and inter-connect studies
- Technology transfer of accelerated archs/apps/techniques of interest to members
- Key insights and lessons learned from design space explorations & tradeoff analyses