DC&N, BDS
N.Brooks, R.Turpin, A.Chappell

# GenATC: Advancing Safety and Efficiency for Autonomous & Manned Vehicles

CS Dept
K.Roy, H.Moradi, S.Green

**Objective:** Create autonomous ATC where human controllers are augmented with AI to help route both manned and unmanned aircraft occupying commercial airspace.

**Approach:** Create Model of Experts (MOE) Large Language Model fined tuned to handle ATC tasks including proactive communications with pilots on approach, departure, taxi, and flyover based on transponder data & predicted trajectory. Design digital twin of commercial airport and model traffic in and out in order to demonstrate safe autonomous and manned aircraft operation, increased capacity and anomaly resolution.

**Benefit:** Advanced insight into commercial autonomous aircraft design and legacy aircraft augmentation including transponder design. Demonstrate how Boeing products play a pivotal role in enhancing ATC capacity in both manned and unmanned products

*Boeing Gen-Twin ATC (GT-ATC)*

# Gen-AI for Air Traffic Control Enhancement: Advancing Safety and Communication Efficiency for Autonomous & Manned Vehicles

PIs: Dr. Hamidreza MORADI, Dr. Kaushik ROY
PhD. Student: Stefan Green

North Carolina Agricultural and Technical State University

# Outline

- Introduction/Motivation
- Related Works & Limitations
- Problem Statement
- Proposed System Architecture
    - Digital Twin
    - LLM
- Proposed Timeline
- Acknowledgment
- References

# *Introduction*

- The International Traffic Association predicts that the quantity of travelling passengers would exceed 4 billion post 2024
  - ATC task: Scheduling flights locally, in the air and on the ground, for coordinated taxing
  - ATC goal: Provide maximum capacity, with most feasible efficiency
  - ATC staff: End up interacting and monitor up to thirty planes over a single time interval
- Deep interest in research on the use of AI in ATC
  - Reduced workload
  - Enhanced scheduling and efficiency
  - Improve management and monitoring
- AI models could be used:
  - Monitoring and Schedule Flights
  - Crew management
  - Flight routing

# *Related Works & Limitations*

- AeroBERT [Ray et al.]
  - Explores potential of using ChatGPT to identify <u>human factors issues</u> from ASRS reporting
  - No preventative measure has been considered. Focuses on safety reporting and analyses
- AviationGPT [Wang et al.]
  - Explores potential use of fine-tuned model on aviation datasets for <u>report querying</u>
  - No real-world live environment testing considered.
- ATCO2 [Gomez et al.]
  - Evaluates the impact of domain shift on <u>speech to text conversation</u> of communication
  - Shows improved performance yet challenging given the pre training and fine tuning phases
- Real world gas turbine anomaly detection [Ma, Y. et al. ]
  - Implements prototype of <u>Turbine Uncertain Performance</u> in a Digital Twin
  - Comparisons are used to generate predictions based on the detected anomalies

# *Challenges*

- Most of the studies solely focus on:
  - Translation
  - Issue classification
  - Small subsystem consideration
- No preventative measure
  - Complexities involved in applying generative AI in ATC settings
  - Limited research addressing these challenges through NLP
- No evaluation in the use of models for
  - Decision making
  - Monitoring and analytical data collection
- Datasets do no provide the context in which event are happened
  - Sparse or limited sources data

# *Problem Statement*

Critical demand for:

- Digital Twin of an Airport
  - To collect the context in which decisions are made
  - Simulate context changes in which the decisions are made

- Robust Generative AI Models
  - Make decisions
  - Monitor operations
  - Present predictive suggestions
  - Perform analytics
  - Provide preventative measures

# Objectives

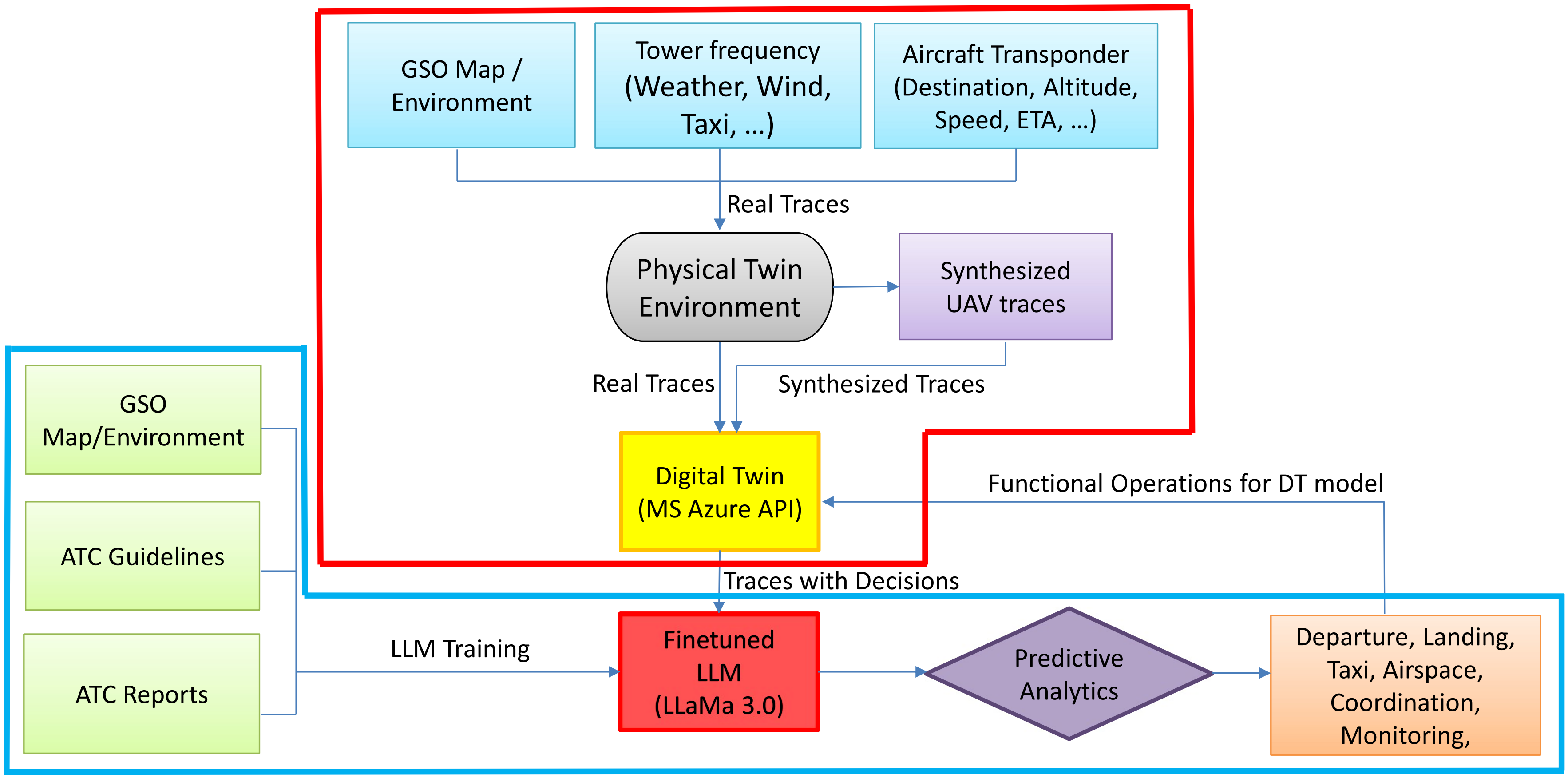
## Develop a Digital Twin of GSO airport:

- Generate a digital twin of a real local airport
- Simulate different scenarios and collect required data
    - The context in which the operation will happen
    - The changes in the existing context
    - Decisions made based on the running context
    - Utilize Digital twin for LLM deployment and testing

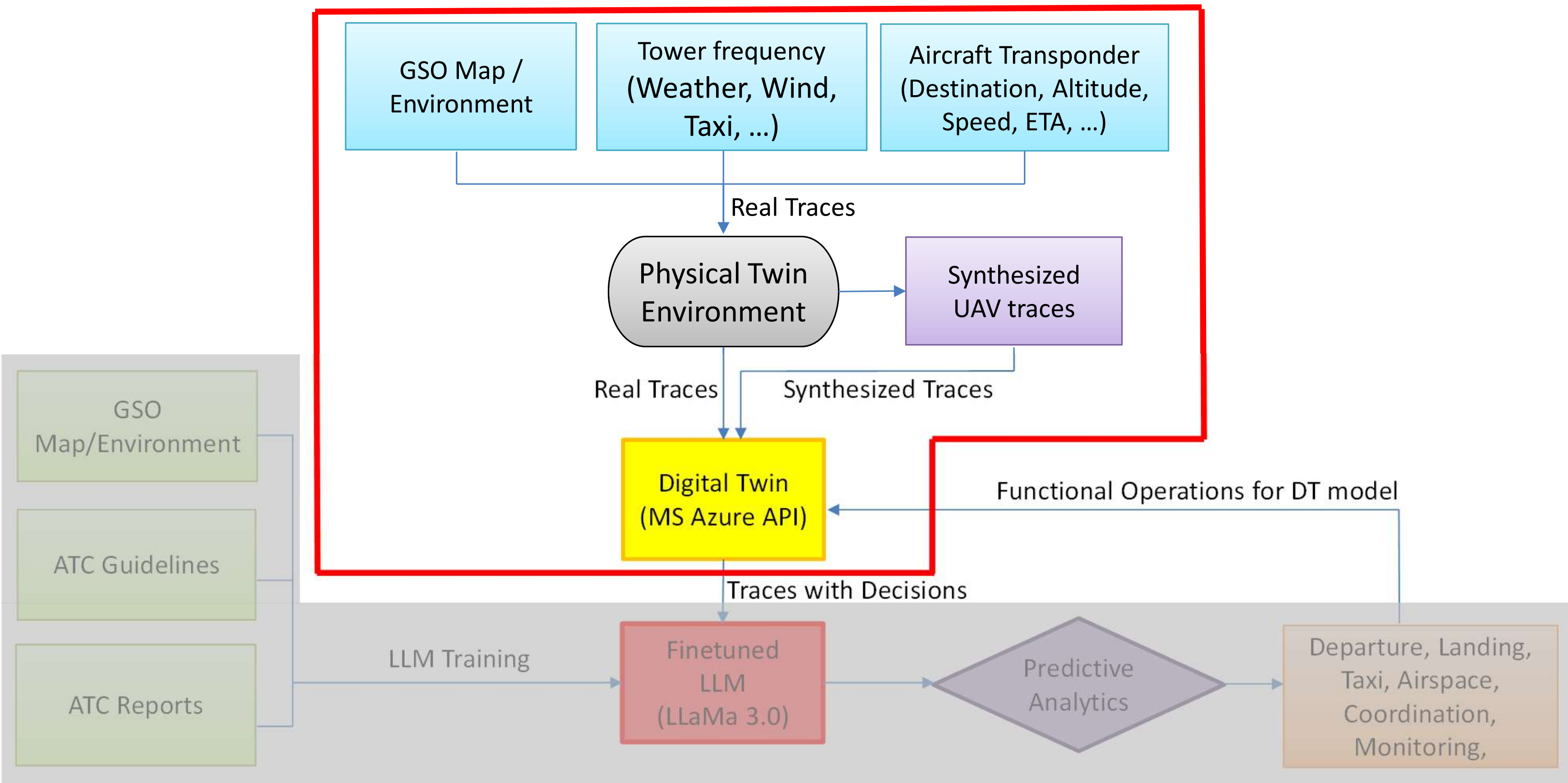
## Train an LLM:

- Understand operations and the required procedure
- Can learn from the existing context and the decisions have been made
    - Navigating air traffic for automation
    - React to changes in the conditions
    - Detect issues

# Proposed System Architecture



# *Proposed System Architecture*

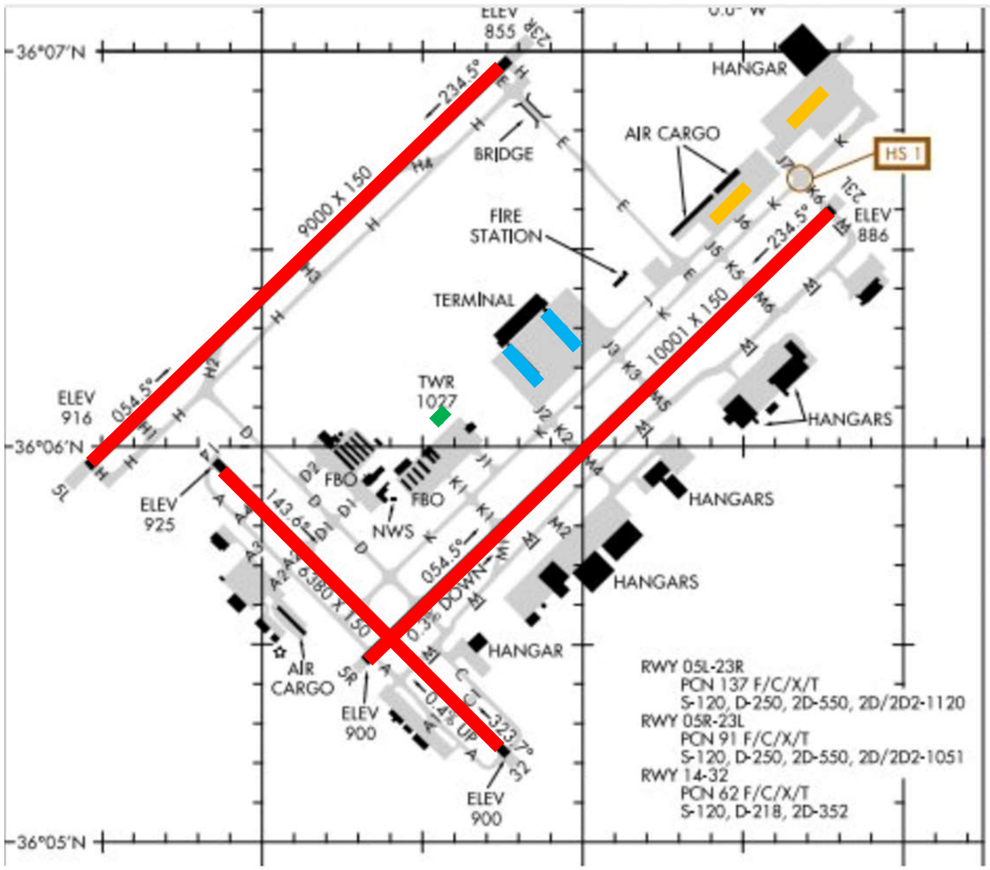


# *Digital Twin*

- Use of classes to represent each object
- Prototype the environment
  - Detail of AP Lanes, ATC environment, tower location
- List of operations/events
  - Surface to air, Air to surface, Taxi, clearance
  - predictive suggestions, monitoring, airspace and traffic coordination

- Generates contextual data
  - From historical context of tower frequencies
    - Arrival/landing of aircrafts with different intervals (close to real events)
    - Wind, temperature, and forecasted weather data
  - With capability of getting inputs for simulation of an even of interest
- Provides actions that should be taken and considered

# GSO Airport Layout



# GSO Airport Photo


North Carolina Agricultural and Technical State University

# Aircraft Transponder

Destination
- Guided destination of  incoming or taxing craft / vehicle

Position
- Current positioning of vehicles on way to and within GSO compound

Altitude
- Current positioning of craft in transit through air

Speed
- Current occurring speed of craft with regards to advised protocol

ETA
- Estimated Time of Arrival for aircraft approaching GSO compound

# *Tower Frequencies*

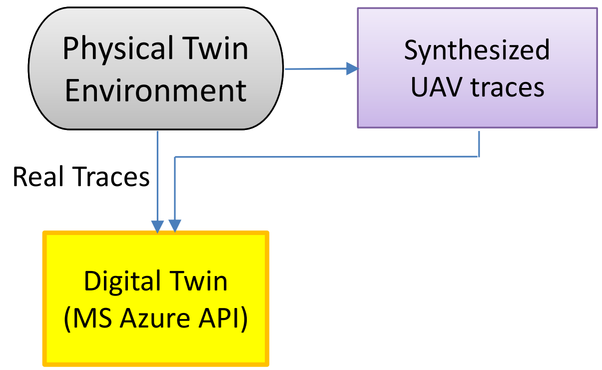
Used for communications with the tower and other airport services :

- ATIS (Automated Terminal Information Service): 128.55 MHz
  - Arrival/Departure
- Ground Control: 121.9 MHz
  - Ground Movement (Taxi, pushback)
- Tower: 119.1 MHz
  - Clearances for takeoff/Landing, Traffic advisories, Instructions for Aircraft in Vicinity
- Approach/Departure (A/D): 118.5 MHz
  - A/D within terminal airspace
- Clearance Delivery (CLD): 121.75 MHz
  - Clearance including routing and altitude
- UNICOM: 122.95 MHz
  - Pilot and ground coordination (fueling, maintenance)

# *Tower Frequencies* *(cont.)*

Provides real data:

- Real traces of Events
- Possibility of artificial generation for UAV based on them

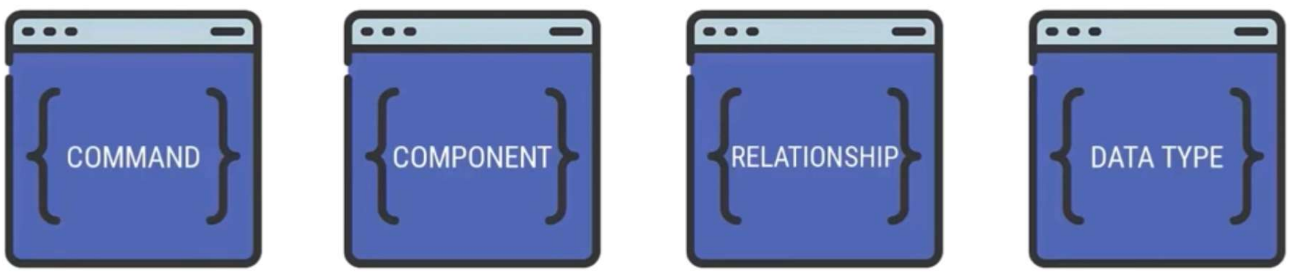


# Microsoft Azure API

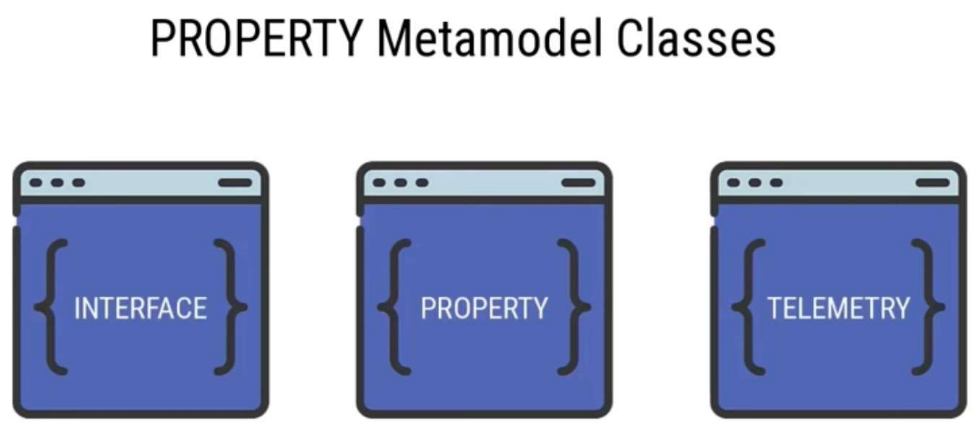
PROPERTY Metamodel Classes

Functions performed by physical entity (Alter Speed)

Components in common (Similar Sensor)

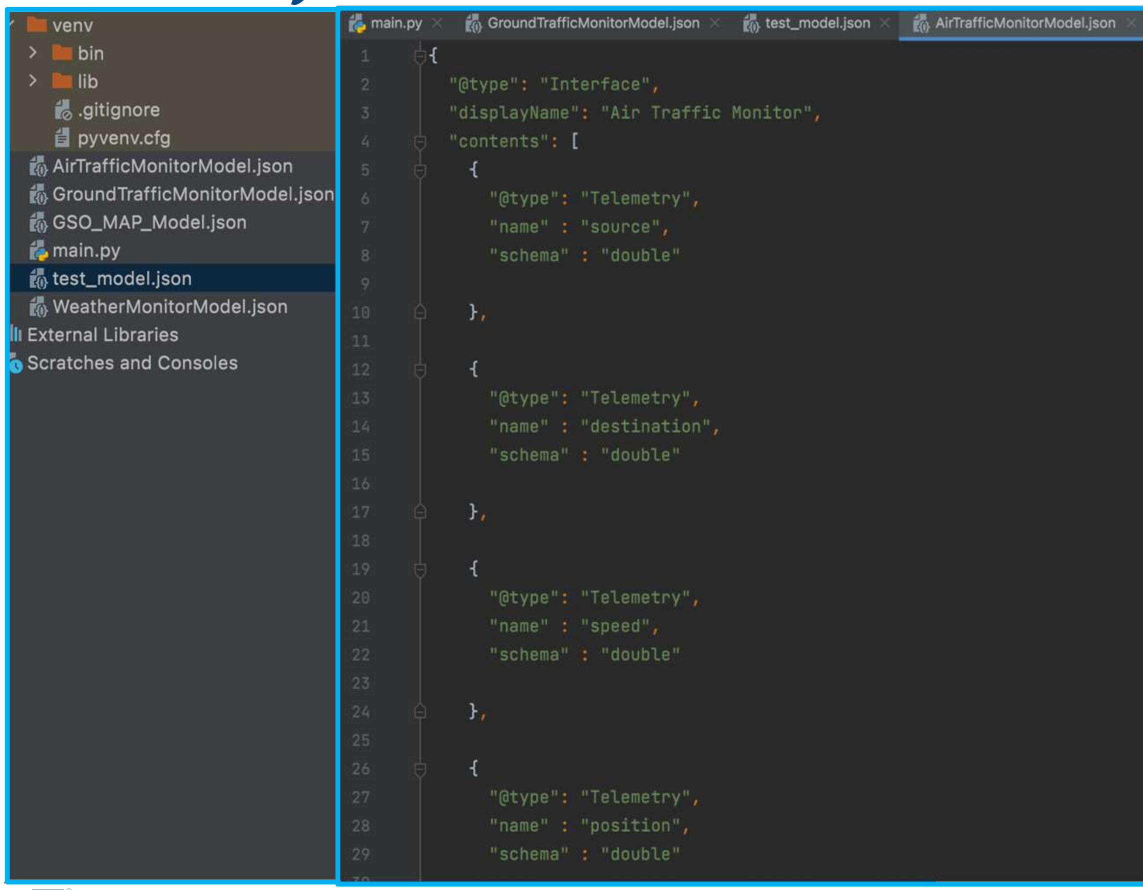


# *Microsoft Azure API*

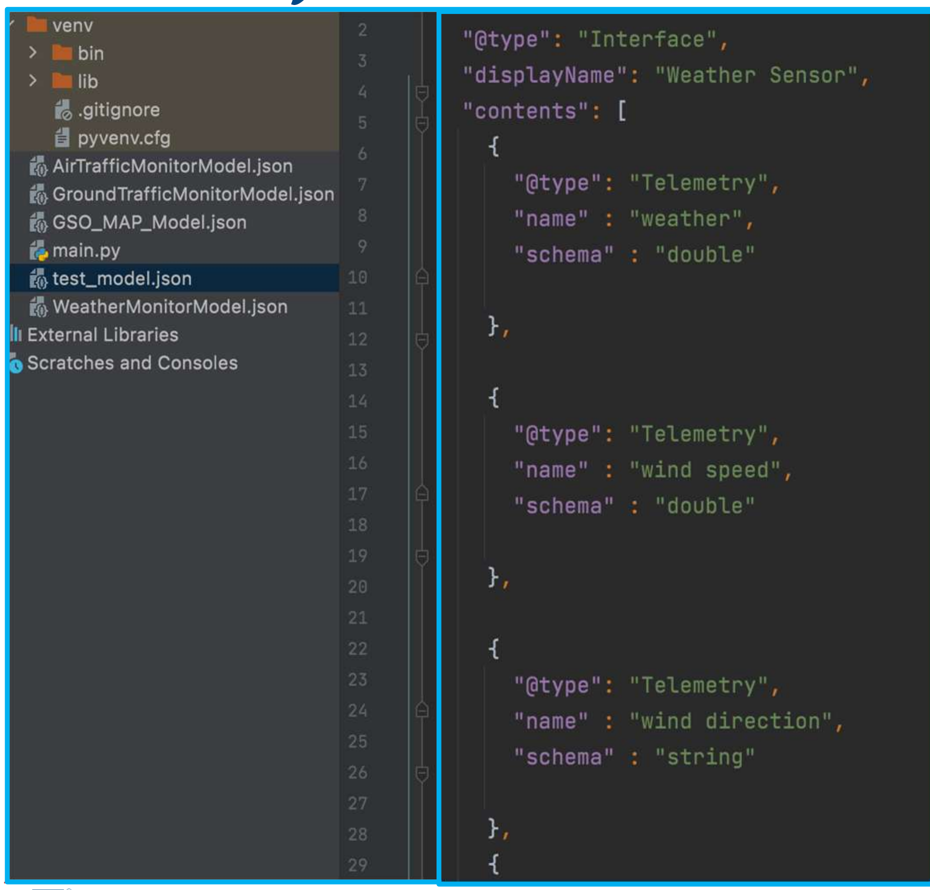



| Enclose all the elements within DT model | Elements that rarely change (Serial Number) | Data emitted by physical entity (Speed, Direction) |
|---|---|---|

# Microsoft Azure API *(cont.)*



# Microsoft Azure API (cont.)



# Microsoft Azure API *(cont.)*

- venv
  - bin
  - lib
  - .gitignore
  - pyvenv.cfg
- AirTrafficMonitorModel.json
- GroundTrafficMonitorModel.json
- GSO_MAP_Model.json
- main.py
- test_model.json
- WeatherMonitorModel.json
- External Libraries
- Scratches and Consoles

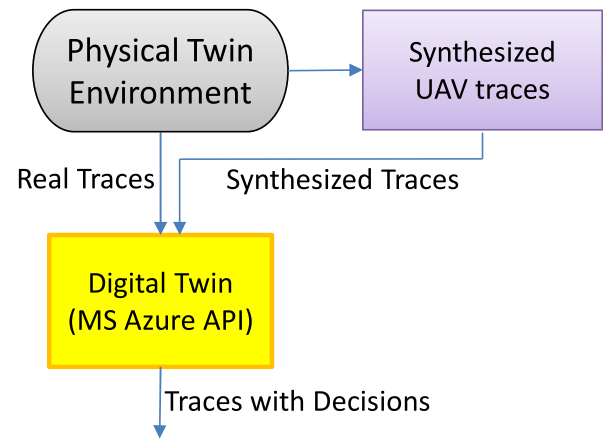
```json
{
  "@type": "Command",
  "name": "provide alert and suggestion",
  "request": {
    "name": "weather detection",
    "displayName": "Weather Monitor",
    "description": "Requested current weather and wind speed",
    "schema": "double"
  },
  "response": {
    "name": "weather telemetry ",
    "schema": " double "
  }
},

{
  "@type": "Command",
  "name": "provide alert and suggestion",
  "request": {
    "name": "wind speed detection",
    "displayName": "Wind Speed Monitor",
    "description": "Requested current wind speed",
    "schema": "double"
```

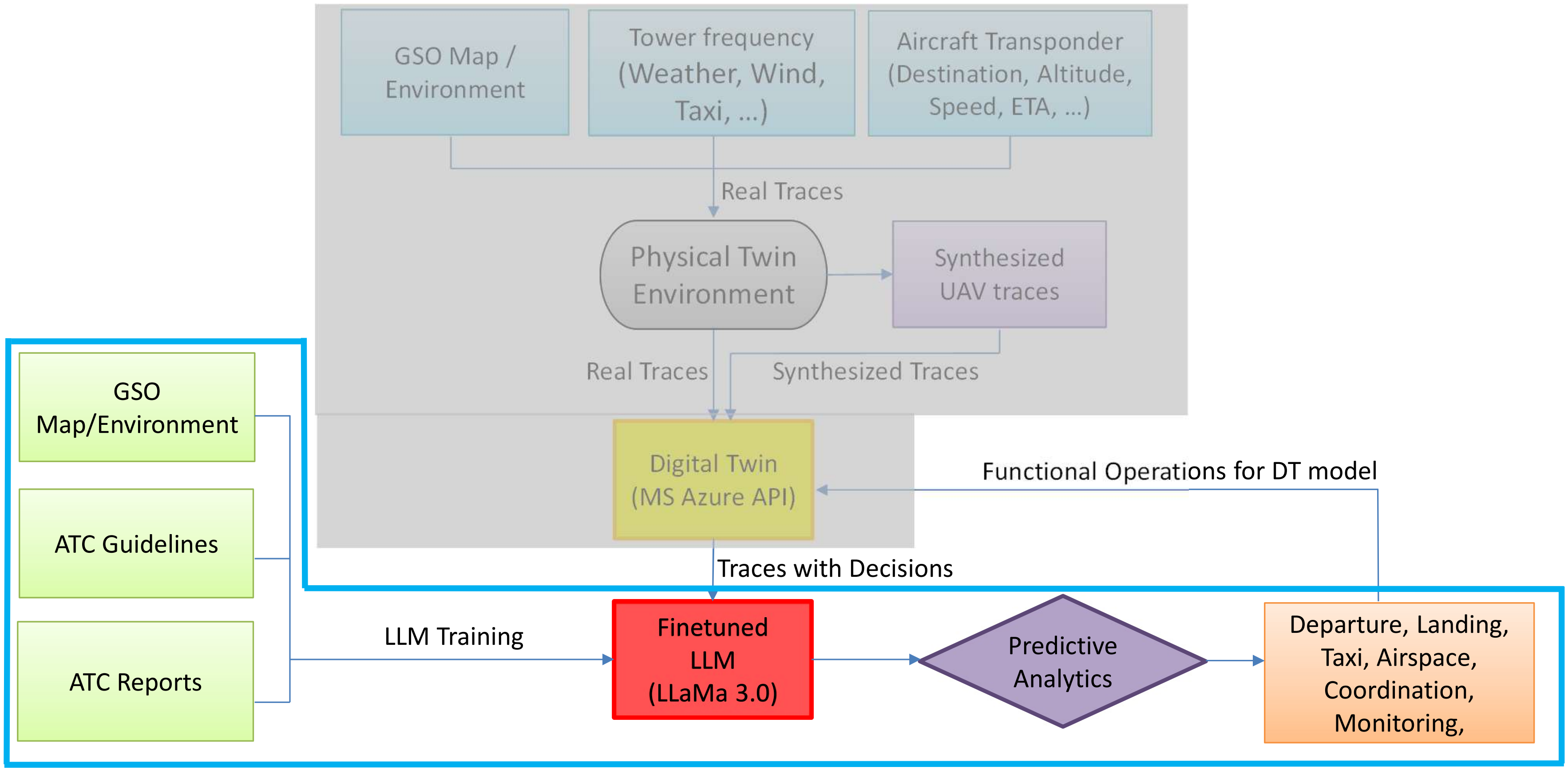
# *Final Output: Traces with Decisions*

Log:

Contextual Data/log 1
Contextual Data/log 2
Contextual Data/log 3
Change in Contextual Data/log 1
Event/Decisions by ATC "A"
Contextual Data/log 4
Contextual Data/log 5
Contextual Data/log 6
Event/Decisions by ATC "B"

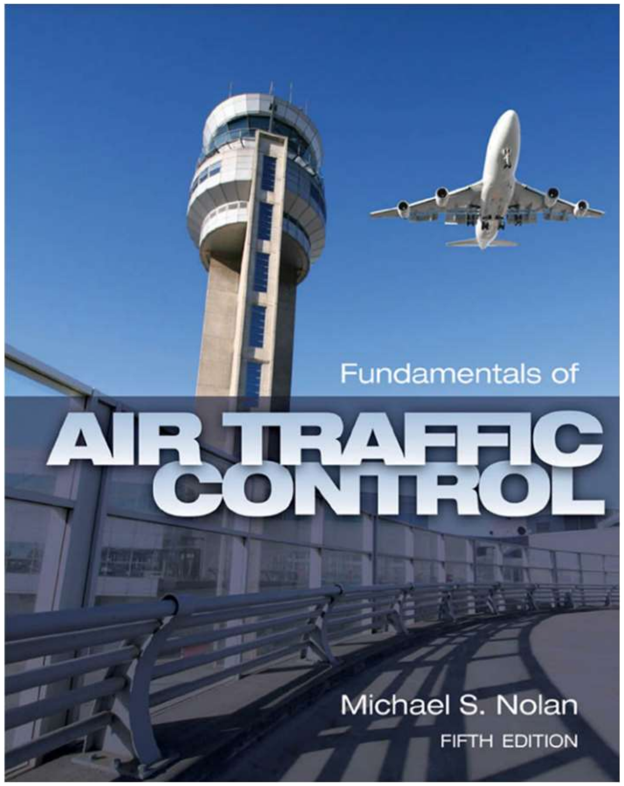


# *Proposed System Architecture*



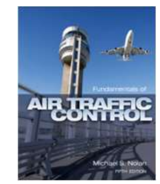
# *LLM for Predictive Suggestions*

- ATC guideline book pretraining
  - GSO Masterplan for providing contextual protocol data



# *LLM for Predictive Suggestions*

- ATC guideline book pretraining
  - GSO Masterplan for providing contextual protocol data



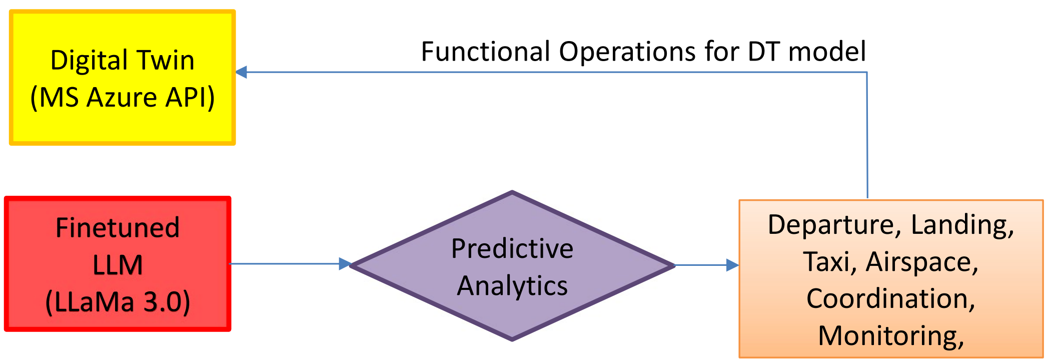

- Designing a model capable of understanding context
  - Using ASR dataset based on ATC narratives
  - Provide understanding of leading cause of issues

- Training on Digital Twin Data
  - Predicting future event/decisions

# *Predictive Analysis*

New Log:

Contextual Data/log 12
Contextual Data/log 13
Contextual Data/log 14
Change in Contextual Data/log 14
Event/Decisions by ATC "C"
Contextual Data/log 4
Contextual Data/log 5
Contextual Data/log 6
**? Event/Decisions by ATC ?**



# *Models & Training Methodologies*

Models:
- Falcon
- LLaMA
- Vicuna

Training Methodologies:
- Fine Tuning & Prompt Engineering
- Parameter Efficient Fine Tuning (PEFT) techniques
  - Prefix-Tunning and LoRA based techniques [QLoRA/LongLoRA])

# *Proposed Timeline*

Task 1:
- Development of Digital Twin
- Data generation for Model Training

Task 2:
- Autonomous Monitoring and Management
- Contextual Modeling for anomaly detection

# Acknowledgment

- Boeing
  - Dr. Nathan Brooks
  - Mr. Arvel Chappell
  - Mr. Raenaurd D. Turpin
- COE
  - Dean Luster-Teasley Pass
  - Ms. Tamera Ziglar

# References


- [1] Ray, A. T., Bhat, A., White, R. T., Nguyễn, V. M., Fischer, O., & Mavris, D. N. (2023). Examining the potential of generative language models for aviation safety analysis: case study and insights using the Aviation Safety Reporting System (ASRS). Aerospace, 10(9), 770. https://doi.org/10.3390/aerospace10090770

- [2] Wang, L., Chou, J., Zhou, X., Tien, A., & Baumgartner, D. (2023). AviationGPT: a large language model for the aviation domain. arXiv (Cornell University). https://doi.org/10.48550/arxiv.2311.17686

- [3] Zuluaga-Gómez, J., Veselý, K., Szöke, I., Motlíček, P., Kocour, M., Rigault, M., Choukri, K., Prasad, A., Sarfjoo, S. S., Nigmatulina, I., Cevenini, C., Kolčárek, P., Tart, A., & Černocký, J. (2022b). ATCO2 corpus: A Large-Scale Dataset for Research on Automatic Speech Recognition and Natural Language Understanding of Air Traffic Control Communications. arXiv (Cornell University). https://doi.org/10.48550/arxiv.2211.04054

- [4] Zuluaga-Gómez, J., Prasad, A., Nigmatulina, I., Sarfjoo, S. S., Motlíček, P., Kleinert, M., Helmke, H., Ohneiser, O., & Zhan, Q. (2023). How Does Pre-Trained Wav2Vec 2.0 Perform on Domain-Shifted Asr? an Extensive Benchmark on Air Traffic Control Communications. 2022 IEEE Spoken Language Technology Workshop (SLT). https://doi.org/10.1109/slt54892.2023.10022724

- [5] Ma, Y., Lee, S., Lu, J., Pan, Y., & Sun, J. (2023). Construction of Data-Driven Performance Digital Twin for a Real-World gas Turbine anomaly Detection considering uncertainty. Sensors, 23(15), 6660. https://doi.org/10.3390/s23156660

## *Thank you!*