Implementing a Multi-Agent Planning System for Martian Exploration

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Master in Artificial Intelligence

Team members:

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Introduction to the Problem

Scientific Goals

High Priority	Medium Priority	Low Priority
Measure radiation levels in sandy terrain at node N12, N86 and N1.	Air dust sample collection during flight over N33 crater.	Capture panoramic images of crater terrain at nodes N5, N58, N121 and N150.
Collect subsurface samples from rocky terrain near nodes N70 and N102.	Detect organic molecules in icy terrain at N59.	Identification of thermal anomalies at icy nodes N56 and N112.
Deploy seismic sensors at the rocky node N20.	Map CO_2 frost coverage in icy areas N53, N63 and N108.	

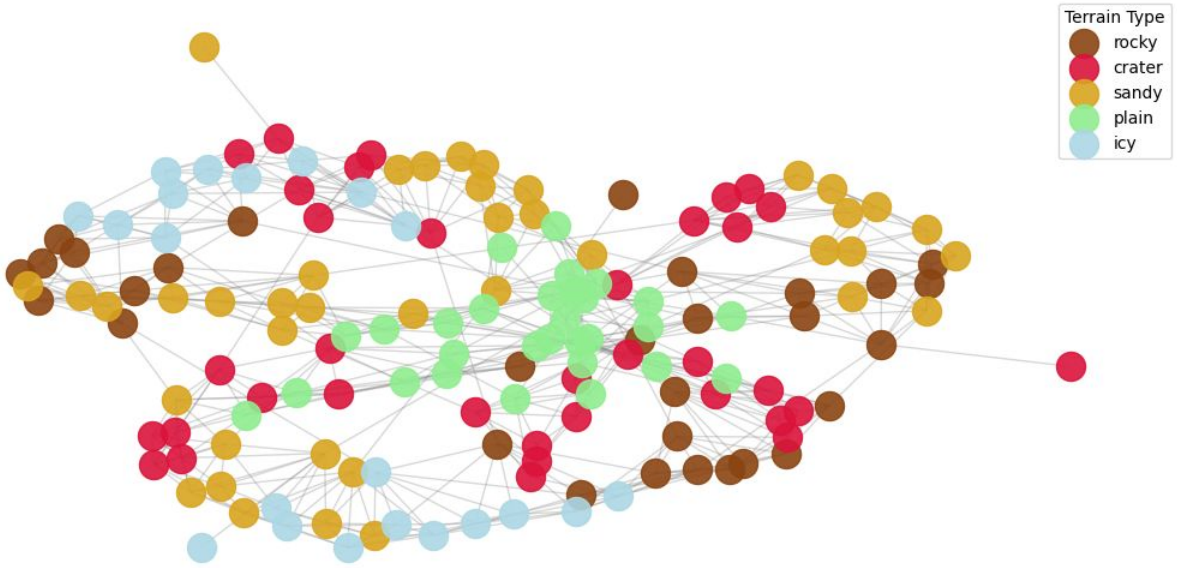
Operational Constraints

- **Rovers**
  - Must enter a heat shelter during 20 minutes if the surface temperature is below -60°C and cannot operate if node temperature is below -80°C.
  - Energy consumption is different depending on the type of terrain.
  - May not operate in terrain classified as unstable or radioactive.
- **Rovers** and **drones** should recharge if energy drops below 30%
- **Drones**
  - Must return to base after 25 minutes of flight.
  - Disabled if there is a dust storm.
  - Cannot operate if wind gusts are higher than 40 km/h
  - Energy consumption is increased 15% if wind is higher than 30 km/h.
- **Satellites**
  - Must maintain communication with the base station at N30 or N84 every 5 hours if they have to identify thermal anomalies.
  - Cannot communicate in nodes with communication loss.

Introduction to the Problem

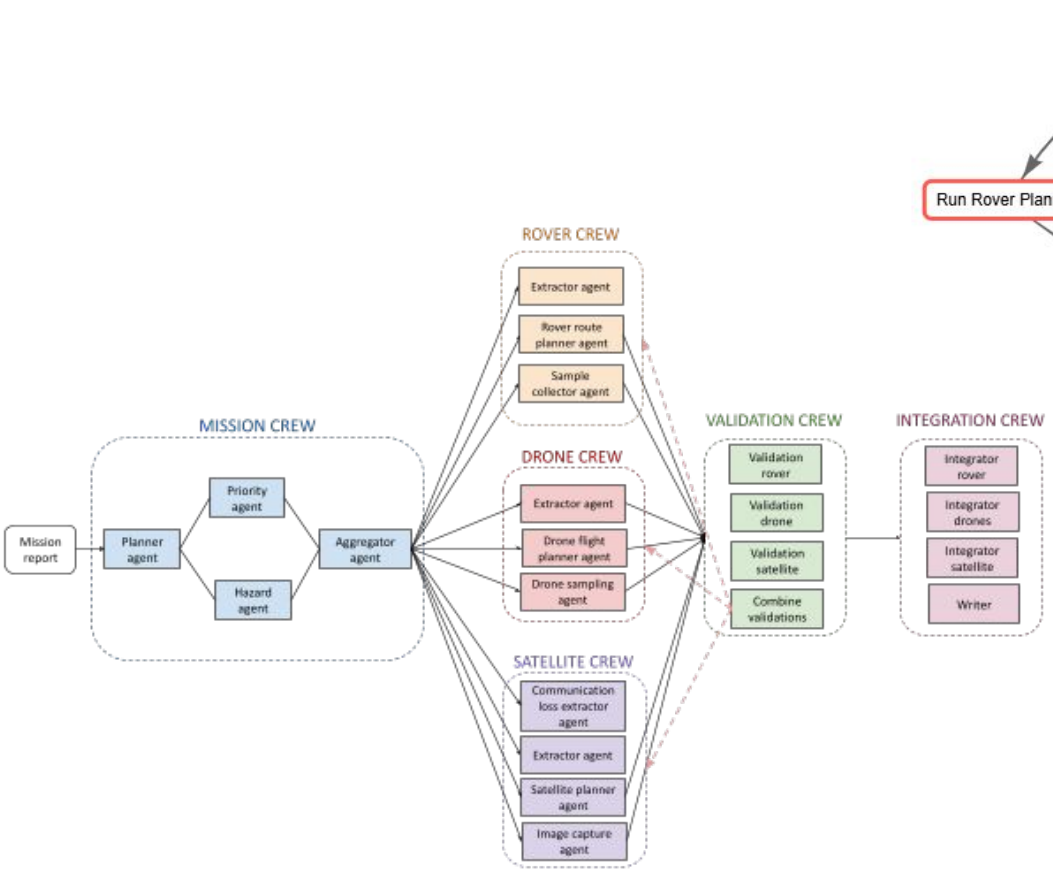
Known Hazards

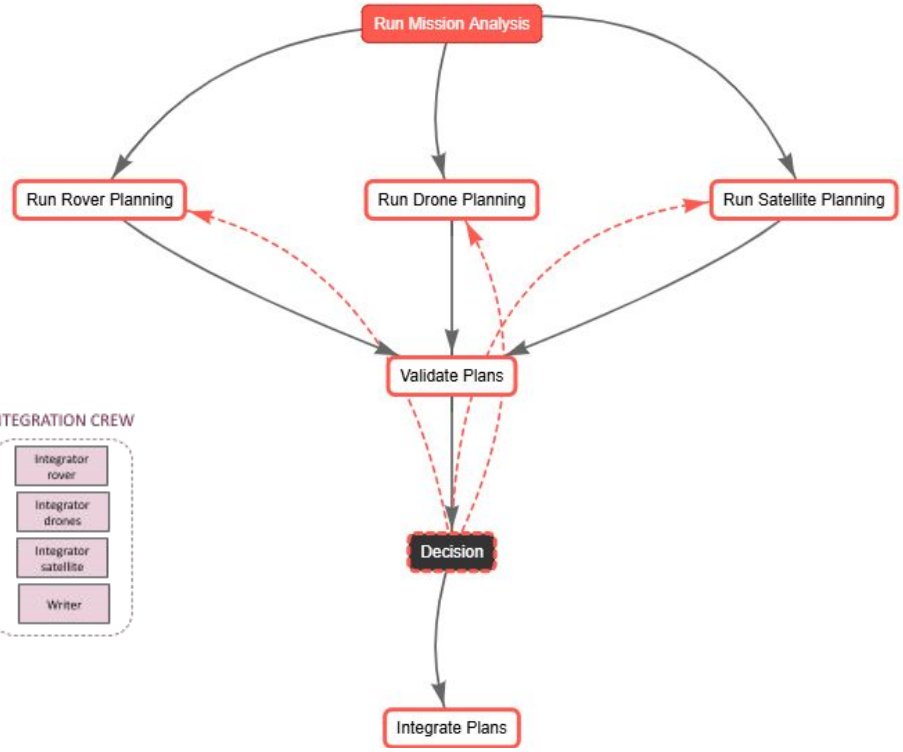
- Nodes N4, N19, N128: unstable rocky terrain.
- Nodes N51, N78, N118: radioactive terrain.
- Node N33: frequent dust storms.



Base: N30, N84

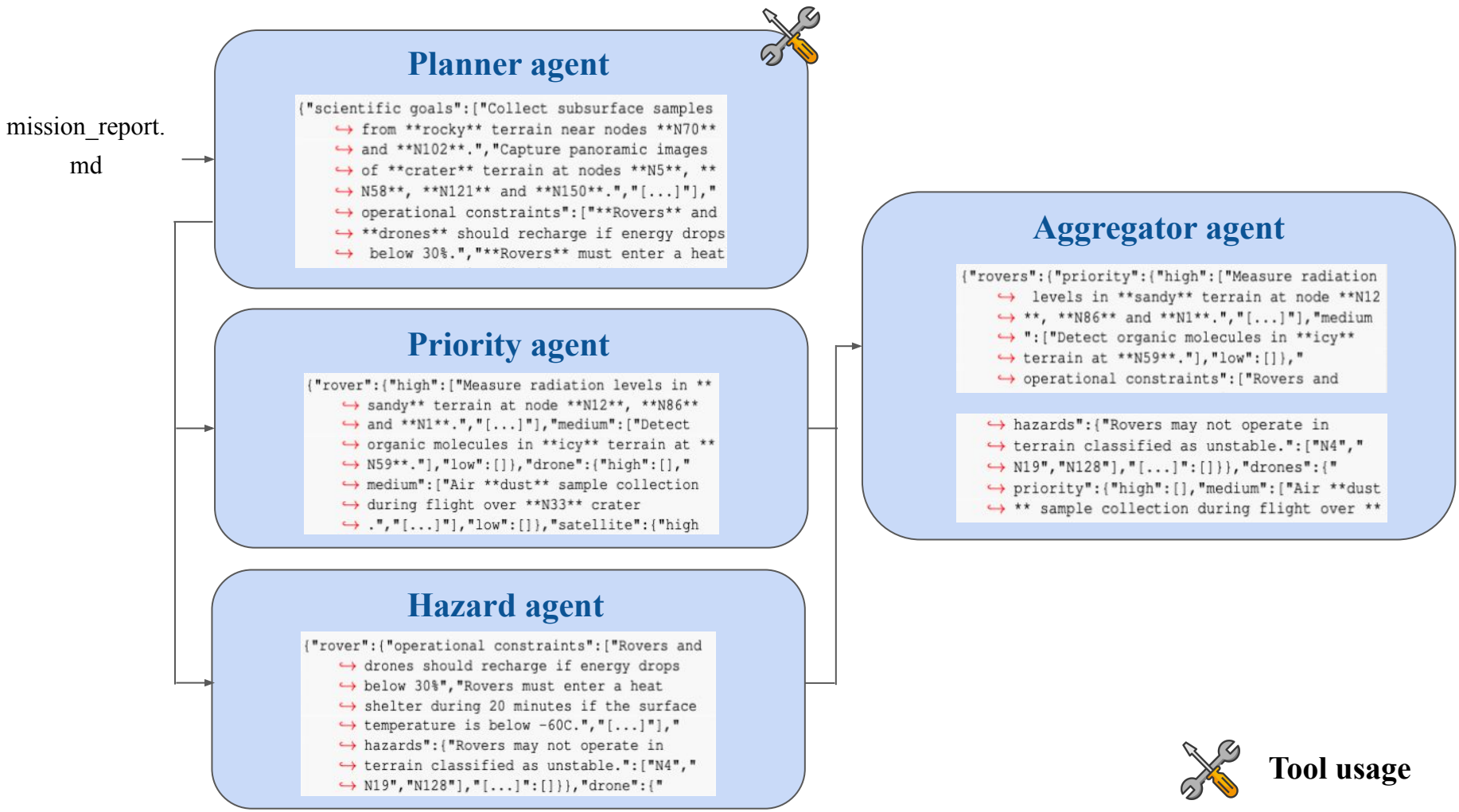
Flow





Start Method | Method | Crew Method | Router | Trigger | AND Trigger | Router Trigger

Mission Crew



Rover Crew

report_priority.json

rover.json

Extractor agent

```
Final Answer:
["N1", "N12", "N20", "N70", "N86", "N102", "N59"]
```

Rover route planner agent


```
{
  "results": {
    "rover_0": [
      [
        "N30", "N28", "N23", "N20", "N25", "N30"
      ],
      [
        "N30", "N28", "N23", "N18", "N13", "N11",
            ↪ "N9", "N4", "N2", "N1", "N6", "N8",
            ↪  "N13", "N18", "N23", "N28", "N30"
      ]
    ],
    "rover_1": [
      [
        "N84", "N85", "N86", "N84"
      ],
```

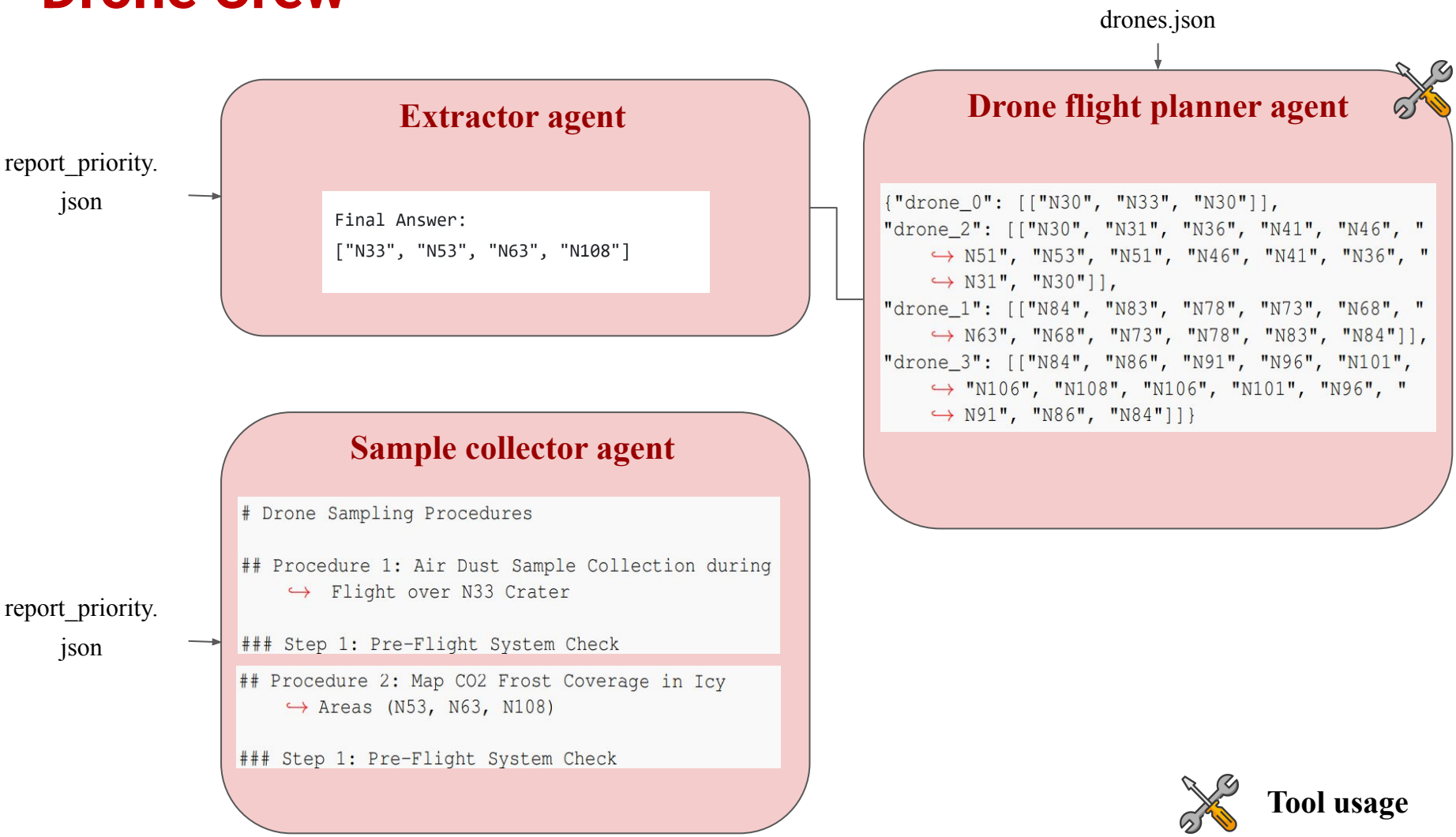

report_priority.json

Sample collector agent

```
# Rover Sampling Protocol Document

## 1. Measure Radiation Levels in Sandy Terrain
    ↪ at Nodes N12, N86, and N1

## 2. Collect Subsurface Samples from Rocky
    ↪ Terrain Near Nodes N70 and N102

### Step-by-Step Procedure:

1. **Rover Navigation**: Traverse to node N70
    ↪ using pre-loaded terrain maps.
```

Tool usage

Drone Crew


drones.json
report_priority.
json
Extractor agent
Final Answer:
["N33", "N53", "N63", "N108"]
Drone flight planner agent
{"drone_0": [["N30", "N33", "N30"]],
"drone_2": [["N30", "N31", "N36", "N41", "N46", "
↪ N51", "N53", "N51", "N46", "N41", "N36", "
↪ N31", "N30"]],
"drone_1": [["N84", "N83", "N78", "N73", "N68", "
↪ N63", "N68", "N73", "N78", "N83", "N84"]],
"drone_3": [["N84", "N86", "N91", "N96", "N101",
↪ "N106", "N108", "N106", "N101", "N96", "
↪ N91", "N86", "N84"]]}
report_priority.
json
Sample collector agent
Drone Sampling Procedures
Procedure 1: Air Dust Sample Collection during
↪ Flight over N33 Crater
Step 1: Pre-Flight System Check
Procedure 2: Map CO2 Frost Coverage in Icy
↪ Areas (N53, N63, N108)
Step 1: Pre-Flight System Check
Tool usage

Satellite Crew

report_hazard_constraints.md

satellite.json

mars_terrain_graph. graphml

report_priority. json

report_priority. json

Communication loss extractor agent

```
Final Answer:
Nodes with Communication Loss: N7, N78, N150
```

Extractor agent

```
Final Answer:
["N5", "N58", "N121", "N150", "N56", "N112"]
```

Image capture agent

```
↪ Panoramic Image Capture for Crater Terrain
↪ } \ &\text{Step 1: Sensor Initialization -
↪  Power on the satellite's camera and
↪ ensure all systems are operational.} \ &\
↪ text{Step 2: Positioning - Manually or
↪ automatically position the satellite over
↪ nodes N5, N58, N121, and N150, checking
↪ for communication signals.} \ &\text{Step
↪ 3: Capture Sequence - Acquire high-
```

Satellite planner agent (provided)

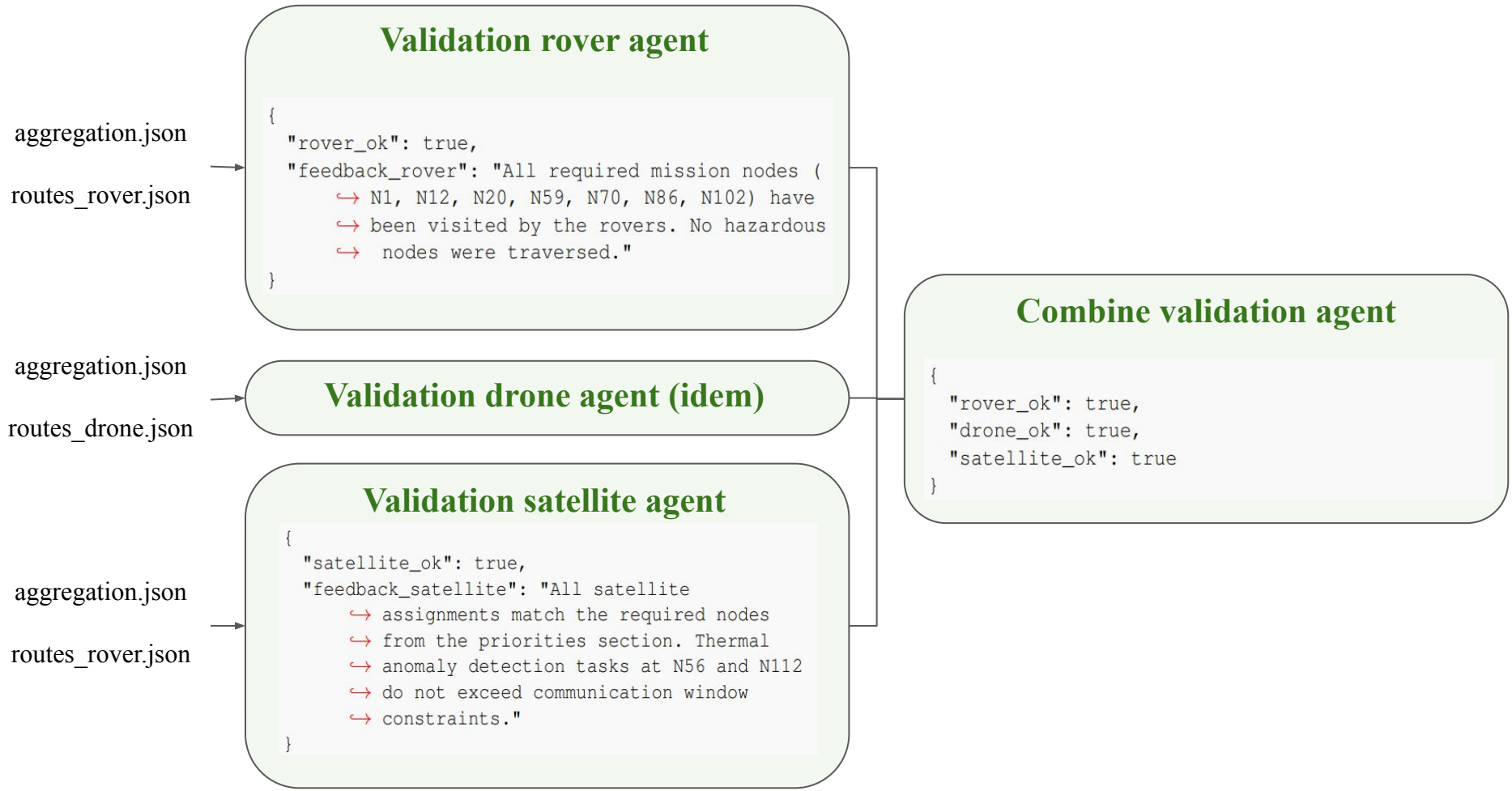
```
{"assignments":[{"id":"Satellite_0","goal":"","
    ↪ location":"N5","communication_window
    ↪ ":""},{"id":"Satellite_1","goal":"","
    ↪ location":"N58","communication_window
    ↪ ":""},{"id":"Satellite_2","goal":"","
    ↪ location":"N121","communication_window
    ↪ ":""},{"id":"Satellite_3","goal":"","
    ↪ location":"N150","communication_window
    ↪ ":""},{"id":"Satellite_4","goal":"","
    ↪ location":"N56","communication_window
    ↪ ":""},{"id":"Satellite_5","goal":"","
    ↪ location":"N112","communication_window
    ↪ ":""}]}
```

Satellite planner agent (ideally)

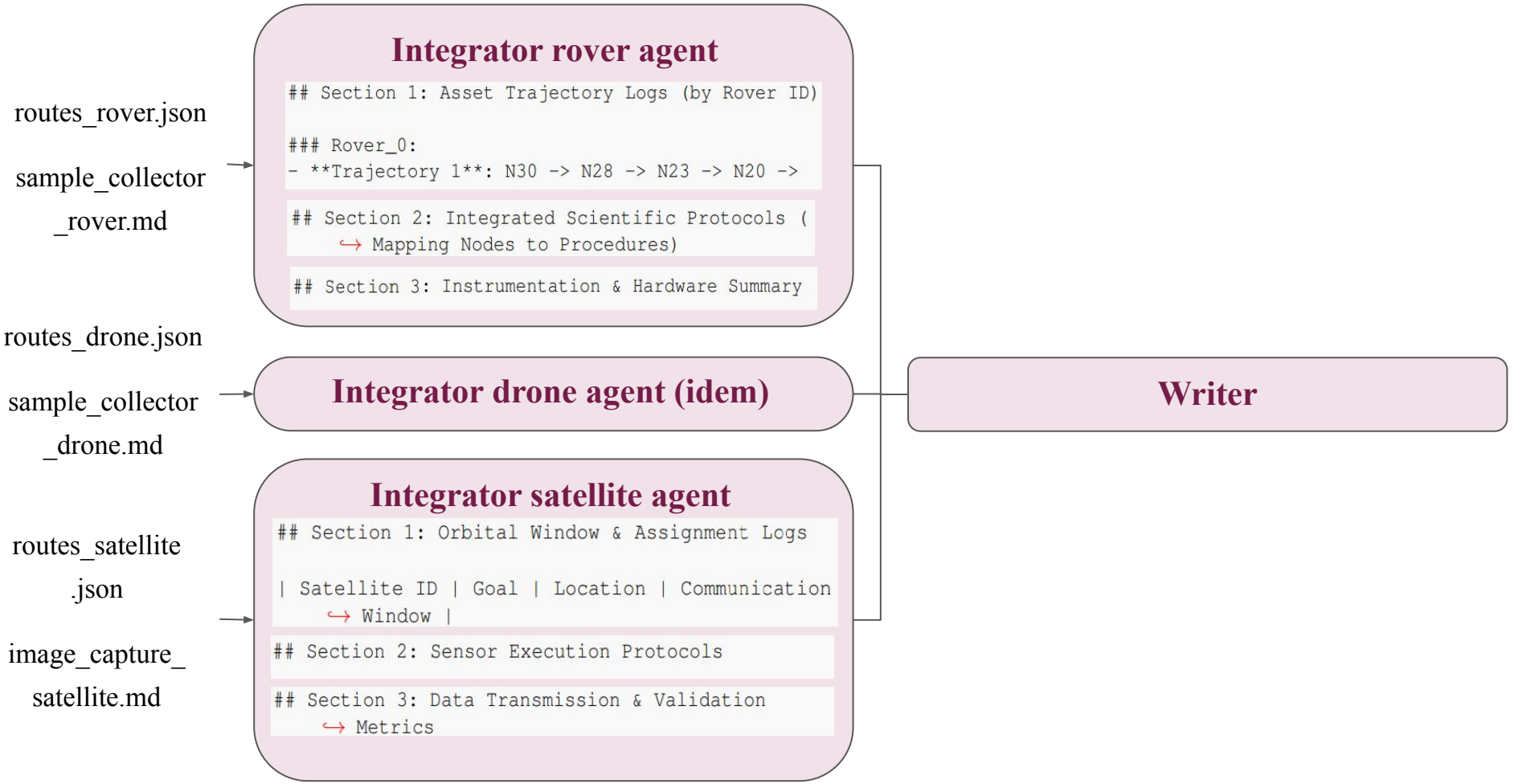
```
{"id":"Satellite_0","goal":"N5","location":"N5","
    ↪ communication_window":7}
{"id":"Satellite_1","goal":"N58","location":"N58
    ↪ ","communication_window":8}
```

Tool usage

Validation Crew



Integration Crew



Final Output Report

Single .md file with 5 sections:

SECTION 1

Table of contents

SECTIONS 2,3,4

Surface, aerial and orbital reports

- ➔ Trajectories or Assignment Logs
- ➔ Scientific or Execution Protocols
- ➔ Instrumentation or Data Transmission

SECTION 5

Conclusion

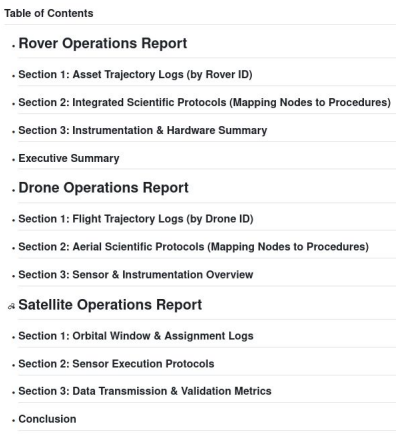
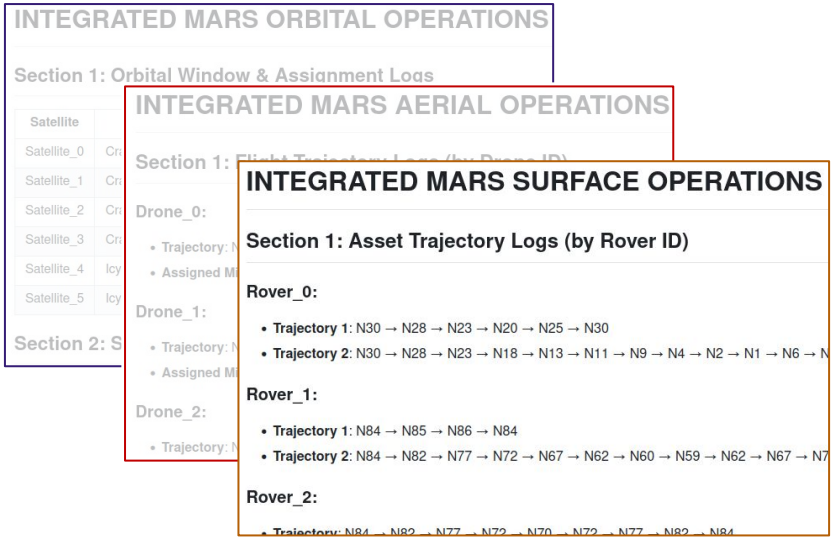


Table of Contents

- Rover Operations Report
  - Section 1: Asset Trajectory Logs (by Rover ID)
  - Section 2: Integrated Scientific Protocols (Mapping Nodes to Procedures)
  - Section 3: Instrumentation & Hardware Summary
  - Executive Summary
- Drone Operations Report
  - Section 1: Flight Trajectory Logs (by Drone ID)
  - Section 2: Aerial Scientific Protocols (Mapping Nodes to Procedures)
  - Section 3: Sensor & Instrumentation Overview
- Satellite Operations Report
  - Section 1: Orbital Window & Assignment Logs
  - Section 2: Sensor Execution Protocols
  - Section 3: Data Transmission & Validation Metrics
  - Conclusion


INTEGRATED MARS ORBITAL OPERATIONS

Section 1: Orbital Window & Assignment Logs

Satellite	
Satellite_0	Cri
Satellite_1	Cri
Satellite_2	Cri
Satellite_3	Cri
Satellite_4	Icy
Satellite_5	Icy

Section 2: S

INTEGRATED MARS AERIAL OPERATIONS

Section 1: Flight Trajectory Logs (by Drone ID)

Drone_0:

- Trajectory: N
- Assigned M

Drone_1:

- Trajectory: N
- Assigned M

Drone_2:

- Trajectory: N

INTEGRATED MARS SURFACE OPERATIONS

Section 1: Asset Trajectory Logs (by Rover ID)

Rover_0:

- Trajectory 1: N30 → N28 → N23 → N20 → N25 → N30
- Trajectory 2: N30 → N28 → N23 → N18 → N13 → N11 → N9 → N4 → N2 → N1 → N6 → N

Rover_1:

- Trajectory 1: N84 → N85 → N86 → N84
- Trajectory 2: N84 → N82 → N77 → N72 → N67 → N62 → N60 → N59 → N62 → N67 → N7

Rover_2:

- Trajectory: N84 → N82 → N77 → N72 → N70 → N72 → N77 → N82 → N84


Conclusion

The MARS JOINT OPERATIONS mission is fully operational across surface, aerial, and orbital platforms. All systems have been successfully integrated, and data transmission protocols are validated. The mission is ready for execution.

Discussion and Limitations

Variable behavior of the agents ⇢

> 40 executions

Common initial errors

- × hallucinations
- × format errors
- × ignoring the provided tools

→ Iteratively refine and test **agent prompts**
→ **Tools** (usage in the task)
→ **Pydantic** outputs

Result

all crews can:
- ✓ work individually
- ✓ produce the expected results

Execution of the whole system:
Validation crew (router)
to solve inconsistencies

2 plans
- with hazards ← contingency
- without hazards

Conclusions

Multi agent systems: automatize or help in the development of plans

➔ Agents are extremely susceptible to:
- prompts
- previous results and formats

➔ Guide the system and converge towards generally valid plans
- prompt refinement
- custom tools + Pydantic outputs

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