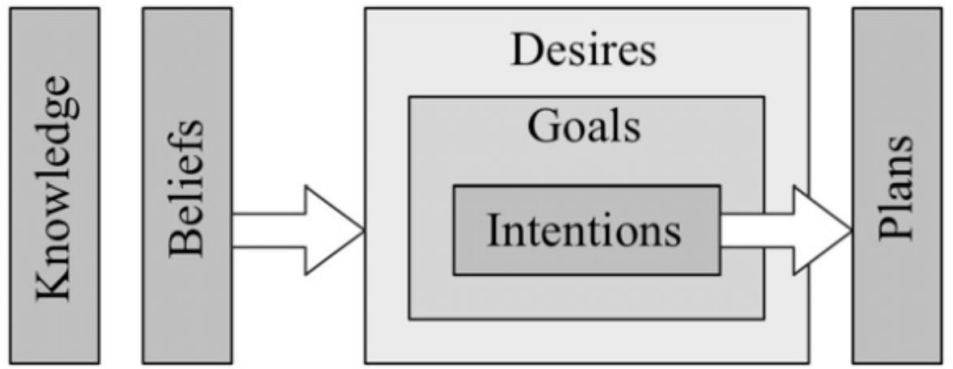
Intelligent Agents Using KQML and KIF

Individual Project

System Overview & Unit 6 Link

- Builds on the Unit 6 group design of autonomous data-retrieval agents.
- Guided by the **BDI model** of rational agency (Rao & Georgeff, 1995).
- Reflects current interest in **distributed, cooperative AI** (Xie et al., 2017).
- Emphasises **ethical AI** – transparency, fairness, accountability (Floridi & Cowls, 2019).
- Bridges theory and practice through a Python implementation of agent dialogue.



Source: Barba Guaman et al. (2017), BDI model figure

Architecture & Classes

- Object-oriented design using Python data classes
- Implements lightweight KQML message structure
- Modular, reusable, and testable agent components.

```python
from dataclasses import dataclass, field
from typing import Optional, Dict
import time, uuid

def _now_iso() -> str:
    return time.strftime("%Y-%m-%dT%H:%M:%S", time.gmtime())

@dataclass
class KQMLMessage:
    """
    Why this design:
    - Implements a lightweight version of the KQML (Knowledge Query and Manipulation Language).
    - Demonstrates how agents communicate using performatives and parameters.
    - Designed for clarity and explanation rather than complexity.
    """
    performative: str
    sender: str
    receiver: str
    language: str = "KIF"
    ontology: str = "research-ops-1"
    content: str = ""
    in_reply_to: Optional[str] = None
    reply_with: str = field(default_factory=lambda: f"msg-{uuid.uuid4().hex[:8]}")
    timestamp: str = field(default_factory=_now_iso)
    params: Dict[str, str] = field(default_factory=dict)
```

Agent Communication (KQML + KIF)

- Implements structured agent dialogue via KQML performatives (*ask-one*, *reply*)
- Messages contain metadata for sender, receiver, and ontology context
- Logical content expressed in KIF ensures interpretability and reasoning consistency
- Promotes transparency and traceability in autonomous communication (Finin et al., 1994; Genesereth and Fikes, 1992)
- Supports ethical accountability through explainable message structure (Floridi and Cowls, 2019)

```
# Initialise system
bus = MessageBus()
ext = Extractor()
ret = Retriever()
bus.register(ext)
bus.register(ret)

# Happy path
print("=== HAPPY PATH ===")
ret.start_dialogue("nano")

# Error path (empty query)
print("\n=== ERROR PATH ===")
ret.start_dialogue("")  # should produce an error
```

“Happy Path” Demonstration

- Demonstrates complete communication cycle between Retriever and Extractor.
- Valid data request processed and summarised as structured KIF output.
- Timestamped logs provide auditability and reproducibility
- Confirms successful task fulfilment and agent coordination (Jennings and Bussmann, 2003)
- Output illustrates system transparency and ethical clarity (Gal, 2022)

```
=== HAPPY PATH ===
SEND (ask-one
  :sender Retriever
  :receiver Extractor
  :language KIF
  :ontology research-ops-1
  :reply-with msg-286bcf7d
  :timestamp 2025-10-13T21:30:50
  :content (findPapers "nano"))

RECV (ask-one
  :sender Retriever
  :receiver Extractor
  :language KIF
  :ontology research-ops-1
  :reply-with msg-286bcf7d
  :timestamp 2025-10-13T21:30:50
  :content (findPapers "nano"))

RECV (reply
  :sender Extractor
  :receiver Retriever
  :language KIF
  :ontology research-ops-1
  :reply-with msg-60031a63
  :timestamp 2025-10-13T21:30:50
  :in-reply-to msg-286bcf7d
  :content ((Paper p1) (hasTitle p1 "Nanomaterials Survey") (hasDOI p1 "10.1234/nano.001") (hasSummary p1 "Overview of nanomaterial synt
hesis and properties.")))

RECV (reply
  :sender Extractor
  :receiver Retriever
  :language KIF
  :ontology research-ops-1
  :reply-with msg-60031a63
  :timestamp 2025-10-13T21:30:50
  :in-reply-to msg-286bcf7d
  :content ((Paper p1) (hasTitle p1 "Nanomaterials Survey") (hasDOI p1 "10.1234/nano.001") (hasSummary p1 "Overview of nanomaterial synt
hesis and properties.")))
```

Error Handling & Retry Logic

- Detects invalid or empty queries and returns structured error responses
- Prevents propagation of faulty requests across the network
- Logs each error with timestamps for traceability and recovery
- Implements retry mechanism for message resilience (Bellifemine et al., 2007)
- Meets ethical standard of explicability in AI system behaviour (Floridi and Cowls, 2019)

```
---- SUMMARY ----
- Nanomaterials Survey [10.1234/nano.001]
  Overview of nanomaterial synthesis and properties.

=== ERROR PATH ===
SEND (ask-one
  :sender Retriever
  :receiver Extractor
  :language KIF
  :ontology research-ops-1
  :reply-with msg-fecf2ee6
  :timestamp 2025-10-13T21:30:50
  :content (findPapers ""))

RECV (ask-one
  :sender Retriever
  :receiver Extractor
  :language KIF
  :ontology research-ops-1
  :reply-with msg-fecf2ee6
  :timestamp 2025-10-13T21:30:50
  :content (findPapers ""))

RECV (error
  :sender Extractor
  :receiver Retriever
  :language KIF
  :ontology research-ops-1
  :reply-with msg-aeb821c1
  :timestamp 2025-10-13T21:30:50
  :in-reply-to msg-fecf2ee6
  :content (reason EmptyQuery))

RECV (error
  :sender Extractor
  :receiver Retriever
  :language KIF
  :ontology research-ops-1
  :reply-with msg-aeb821c1
  :timestamp 2025-10-13T21:30:50
  :in-reply-to msg-fecf2ee6
```

Subscriptions & Reasoning

- Demonstrates *subscribe* performative for dynamic updates and ongoing monitoring
- Extractor sends *inform* messages autonomously when new data appears
- Introduces ranking and scoring of results to simulate relevance reasoning
- Embodies proactive and reactive agent traits (Wooldridge and Jennings, 1995)
- Enhances autonomy and adaptiveness within cooperative multi-agent systems (Nguyen et al., 2018)

```python
class Retriever(Agent):
    """Search & Retrieval with pending request map and correlation checks."""
    def __init__(self, name="Retriever"):
        super().__init__(name)
        self.last_answers: List[str] = []
        self.pending: Dict[str, str] = {}  # reply_with -> term

    def start_dialogue(self, term: str):
        ask = KQMLMessage(
            performative="ask-one", sender=self.name, receiver="Extractor",
            content=f'(findPapers "{term}")'
        )
        self.pending[ask.reply_with] = term
        self.send(ask)

    def subscribe_updates(self, term: str):
        sub = KQMLMessage(
            performative="subscribe", sender=self.name, receiver="Extractor",
            content=f'(findPapers "{term}")'
        )
        self.pending[sub.reply_with] = term
        self.send(sub)
```

Testing & Validation

- Automated tests executed using Python unittest framework
- Validates both successful communication and error recovery processes
- Confirms reliable message exchange under normal and fault conditions
- Reinforces system dependability and maintainability (Bellifemine et al., 2007)
- Transparent logging and reproducibility uphold ethical and technical standards (Floridi and Cowls, 2019).

```python
import unittest

class TestAgents(unittest.TestCase):
    def setUp(self):
        self.bus = MessageBus()
        self.ext = Extractor()
        self.ret = Retriever()
        self.bus.register(self.ext)
        self.bus.register(self.ret)

    def test_happy_path_returns_facts(self):
        self.ret.start_dialogue("nano")
        combined = " ".join(self.ret.last_answers)
        self.assertIn("hasDOI", combined)

    def test_error_on_empty_query(self):
        self.ret.start_dialogue("")
        self.assertTrue(any(ans.startswith("ERROR ") for ans in self.ret.last_answers))

suite = unittest.TestLoader().loadTestsFromTestCase(TestAgents)
unittest.TextTestRunner(verbosity=2).run(suite)
```

```
test_error_on_empty_query (__main__.TestAgents.test_error_on_empty_query) ... ok
test_happy_path_returns_facts (__main__.TestAgents.test_happy_path_returns_facts) ... ok

----------------------------------------------------------------------
Ran 2 tests in 0.012s

OK
```

Limitations & Future Work

- All design goals from Unit 6 successfully implemented in Python: data retrieval, processing, and structured KIF output.
- Agents demonstrated autonomy and cooperation via KQML performatives.
- Fault tolerance and retry logic improved robustness and reliability (Bellifemine et al., 2007).
- Communication remained interpretable, fulfilling ethical transparency standards (Floridi and Cowls, 2019).
- Code modularity and in-line documentation enhanced maintainability and scalability (Jennings and Bussmann, 2003).
- Minor limitations: static dataset and simplified ontology restrict external integration.

Conclusion & Ethical Reflection

- Developed a functional multi-agent system based on KQML and KIF protocols.
- Demonstrated autonomy, communication, and transparency.
- Fulfilled ethical design criteria through interpretability and accountability.
- Provides scalable foundation for responsible AI development.
- Future work: dynamic ontologies, API integration, and adaptive learning mechanisms.

References

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