

The Three Layers of Knowledge Representation

Semantic Web, Ontology, and Knowledge Graph

The Confusion

Students often ask:

- "What's the difference between ontology and knowledge graph?"
- "Isn't semantic web the same as ontology?"
- "When do I use which term?"

Today: Clear understanding of the three layers and how they relate

The Big Picture: Three Layers

SEMANTIC WEB (Layer 3)
The Web of Data – Machine
Readable Internet

Vision & Standards
(W3C, RDF, OWL, SPARQL)

↓

ONTOLOGY (Layer 2)
Domain Model – Classes,
Properties, Rules

Schema & Rules
(Structure, Constraints)

↓

KNOWLEDGE GRAPH (Layer 1)
Actual Facts – Specific
Entities and Relationships

Data & Instances
(Real Information)

Analogy: Building a City

Think of it like city infrastructure:

1. Knowledge Graph (Foundation)

- The actual buildings and roads
- Specific addresses and locations
- Real people living in real houses

Focuses on Data and Instances

2. Ontology (Blueprint)

- Building codes and zoning laws
- "What is a house?" "What is a road?"
- Rules about how things connect

Focuses on Schema and Constraints

3. Semantic Web (National Standards)

- Universal protocols for all cities
- Standard ways to describe locations
- How cities communicate with each other

Focus: Interoperability & Protocols

Layer 1: Knowledge Graph (Data and Instances)

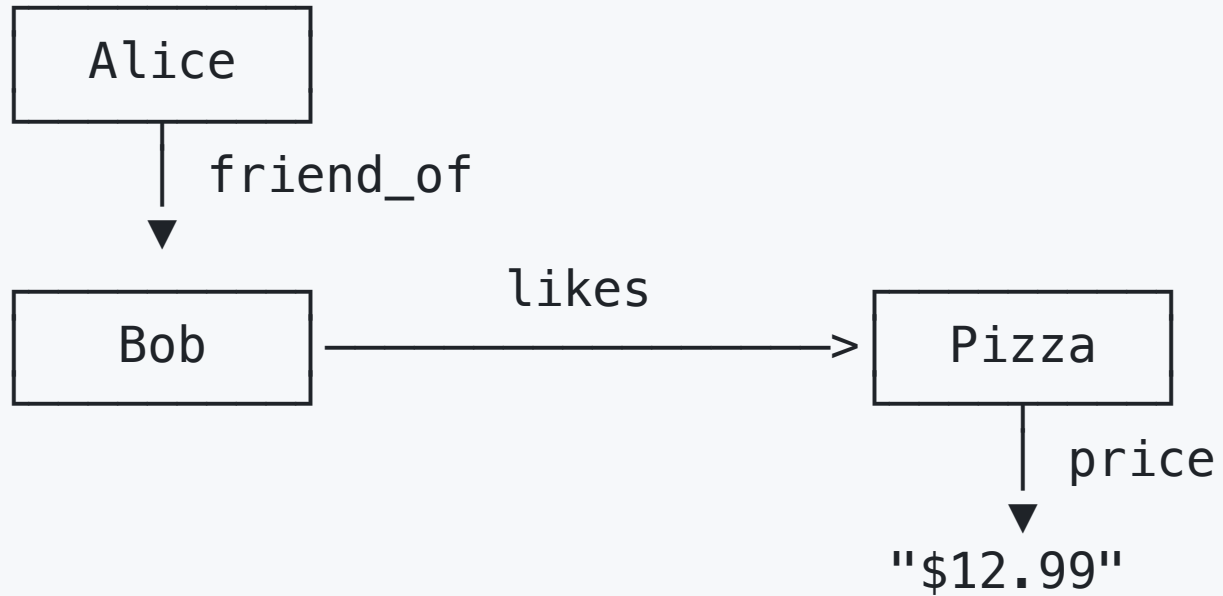
What is it?

A knowledge graph is the actual DATA:

- Specific entities (Alice, Bob, Pizza)
- Concrete relationships (Alice likes Pizza)
- Real-world facts (Pizza costs \$12)

Think: The INSTANCES, not the definitions

Knowledge Graph Example



This is concrete data about specific things

Knowledge Graph in RDF (Turtle)

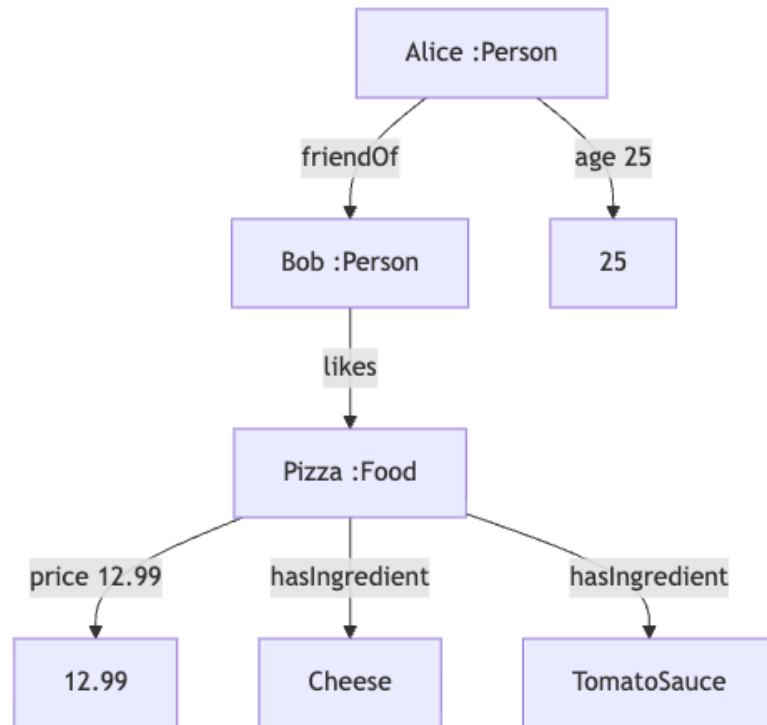
Actual facts about specific entities

```
:Alice rdf:type :Person .  
:Alice :friendOf :Bob .  
:Alice :age 25 .  
  
:Bob rdf:type :Person .  
:Bob :likes :Pizza .  
  
:Pizza rdf:type :Food .  
:Pizza :price 12.99 .  
:Pizza :hasIngredient :Cheese .  
:Pizza :hasIngredient :TomatoSauce .
```

Each line is a FACT about a SPECIFIC thing

Drawing Relationship

We can use a tool, such as Mermaid, to visualize the knowledge graph relationships.



```
graph TD
Alice["Alice :Person"] -->|friendOf| Bob["Bob :Person"]
Alice -->|age 25| AliceAge["25"]

Bob["Bob :Person"] -->|likes| Pizza["Pizza :Food"]

Pizza -->|price 12.99| PizzaPrice["12.99"]
Pizza -->|hasIngredient| Cheese["Cheese"]
Pizza -->|hasIngredient| TomatoSauce["TomatoSauce"]
```

Knowledge Graph Characteristics

✓ **Specific entities** (not types)

- "Alice", "Bob", "This pizza"
- Not "Person in general" or "All pizzas"

You can think of it as: Objects in OOP

✓ **Concrete data**

- "Alice is 25 years old"
- "This pizza costs \$12.99"

You can think of it as: Object methods or attributes in OOP

✓ Individual relationships

- "Alice knows Bob"
- "Bob likes pizza"

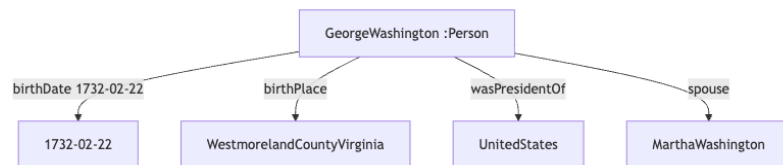
✓ Can be queried

- "Who are Alice's friends?"
- "What does Bob like?"

Real-World Knowledge Graphs

Google Knowledge Graph:

```
:GeorgeWashington rdf:type :Person .  
:GeorgeWashington :birthDate "1732-02-22" .  
:GeorgeWashington :birthPlace :WestmorelandCountyVirginia .  
:GeorgeWashington :wasPresidentOf :UnitedStates .  
:GeorgeWashington :spouse :MarthaWashington .
```



These are **FACTS** about a **SPECIFIC** person

Layer 2: Ontology (Schema and Constraints)

What is it?

An ontology is the SCHEMA (TPRC):

- Defines what TYPES of things exist
- Defines what PROPERTIES they can have
- Defines RULES about relationships
- Provides CONSTRAINTS and validation

Think: The BLUEPRINT or STRUCTURE

- Remember CD in D? Conceptual Description in Domain
- In OOP, it's like a Class Definition
 - "What is a Person?" "What properties can a Person have?"
 - It also describes the hierarchy of classes and relationships between them.

Ontology Example

```
# Ontology defines TYPES and RULES (not specific instances)

# What is a Person?
:Person rdf:type owl:Class .
:Person rdfs:comment "A human being" .
```

This ontology is written in turtle using OWL vocabulary.

- Instead of defining type or comment, we reuse existing one in rdf and rdfs namespaces.
- For example, we use owl:Class to define a class, rdfs:comment to add description, and rdf:type to specify the type of the class.

This is another class definition example: Food

```
# What is a Food?  
:Food rdf:type owl:Class .  
:Food rdfs:comment "Something that can be eaten" .
```

We define the class Food (using owl schema), and we need properties that maps Food to data values.

```
# What properties can a Person have?  
:age rdf:type owl:DatatypeProperty ;  
    rdfs:domain :Person ;  
    rdfs:range xsd:integer ;  
    rdfs:comment "Age must be a positive integer" .
```

Properties (DatatypeProperty or ObjectProperty) define relationships between classes and data values.

In this example, age property maps Person to integer values.

- rdfs:domain is the input class
- rdfs:range is the output datatype

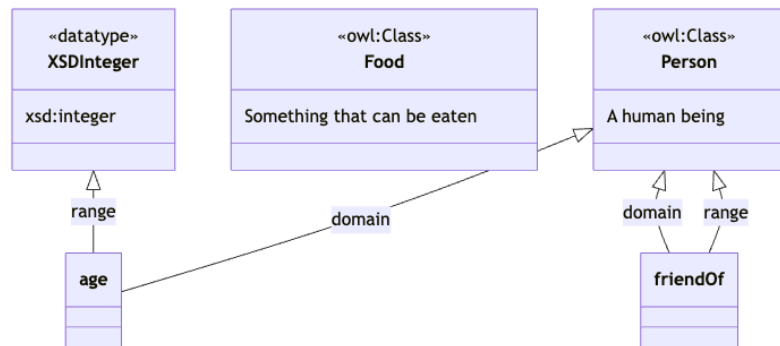
You can think of properties as methods or attributes in OOP.

```
:friendOf rdf:type owl:ObjectProperty ;  
  rdfs:domain :Person ;  
  rdfs:range :Person ;  
  rdfs:comment "Friendship is between persons" .
```

Overall Structure

We have two classes and two properties defined in this ontology.

- The properties define relationships between classes and data values.
- We use xsd:integer to specify that age is an integer datatype.



Ontology Defines Structure

Person (Class)

Properties:

- name: string
- age: integer (≥ 0)
- friendOf: Person



subClassOf

Student (Class)

Additional Properties:

- studentId: string
- major: string

Defines WHAT CAN EXIST, not what DOES EXIST

Ontology vs Knowledge Graph

| Aspect | Ontology | Knowledge Graph |
|---------|---------------------|---------------------|
| Level | Schema/Blueprint | Data/Instances |
| Defines | Types & Rules | Specific Facts |
| Example | "What is a Person?" | "Alice is a person" |
| Purpose | Structure | Content |
| Changes | Rarely | Frequently |
| Size | Small (classes) | Large (millions) |

Side-by-Side Comparison

Ontology (Schema):

```
:Person rdf:type owl:Class .  
:age rdfs:domain :Person ;  
      rdfs:range xsd:integer .
```

"A Person can have an age, which is an integer"

Knowledge Graph (Data):

```
:Alice rdf:type :Person .  
:Alice :age 25 .
```

"Alice is a person and she is 25 years old"

Think of it as Programming

Ontology = Class Definition:

```
class Person {  
    String name;  
    int age;  
    List<Person> friends;  
}
```

Knowledge Graph = Instances:

```
Person alice = new Person();  
alice.name = "Alice";  
alice.age = 25;  
  
Person bob = new Person();  
alice.friends.add(bob);
```


Layer 3: Semantic Web (Interoperability & Protocols)

What is it?

The Semantic Web is the VISION and STANDARDS:

- Web of linked data (not just documents)
- Machines can understand content
- Universal standards for representation
- Interoperability across systems

Think: The PROTOCOLS and INFRASTRUCTURE

Semantic Web: The Big Vision

Tim Berners-Lee's vision (2001):

Traditional Web:

HTML pages → Humans read → Understand

Semantic Web:

RDF data → Machines read → Understand → Act

Goal: Make the web machine-understandable

Semantic Web Stack

| | |
|-------------------------------|--------------------|
| Trust & Proof | Verify information |
| Logic & Rules (SWRL, SHACL) | Reasoning |
| Ontology (OWL) | Define structure |
| Query (SPARQL) | Ask questions |
| Schema (RDFS) | Basic vocabulary |
| Data (RDF) | Facts as triples |
| Syntax (XML, Turtle, JSON-LD) | How to write |
| URI/IRI | Unique identifiers |

Semantic Web Technologies

Standards provided by W3C:

1. **RDF** (Resource Description Framework)

- How to represent data as triples

2. **RDFS** (RDF Schema)

- Basic vocabulary (class, subClass, property)

3. **OWL** (Web Ontology Language)

- Rich ontology definitions

4. **SPARQL** (Query Language)

- How to query RDF data

5. **SHACL** (Shapes Constraint Language)

Triples

In RDF, data is stored as triples (also called triplets).

A triple has three parts: Subject — Predicate — Object

Think of it as a simple sentence:

Example: "Alice likes Pizza."

This becomes an RDF triple:

- Subject → Alice (the thing we talk about)
- Predicate → likes (the relationship)
- Object → Pizza (the value or other thing)

Why Triple Format Is Useful

1. Triples make data:

- Easy for machines to understand
- Easy to connect (link data from different sources)
- Flexible (you can add new facts without changing structure)

2. You can remember RDF triples like this:

- Thing → Relationship → Value
- Who → Does what → To whom/what

Semantic Web: Universal Standards

Why standards matter:

Without standards:

```
Company A: uses "firstName"  
Company B: uses "given_name"  
Company C: uses "name_first"
```

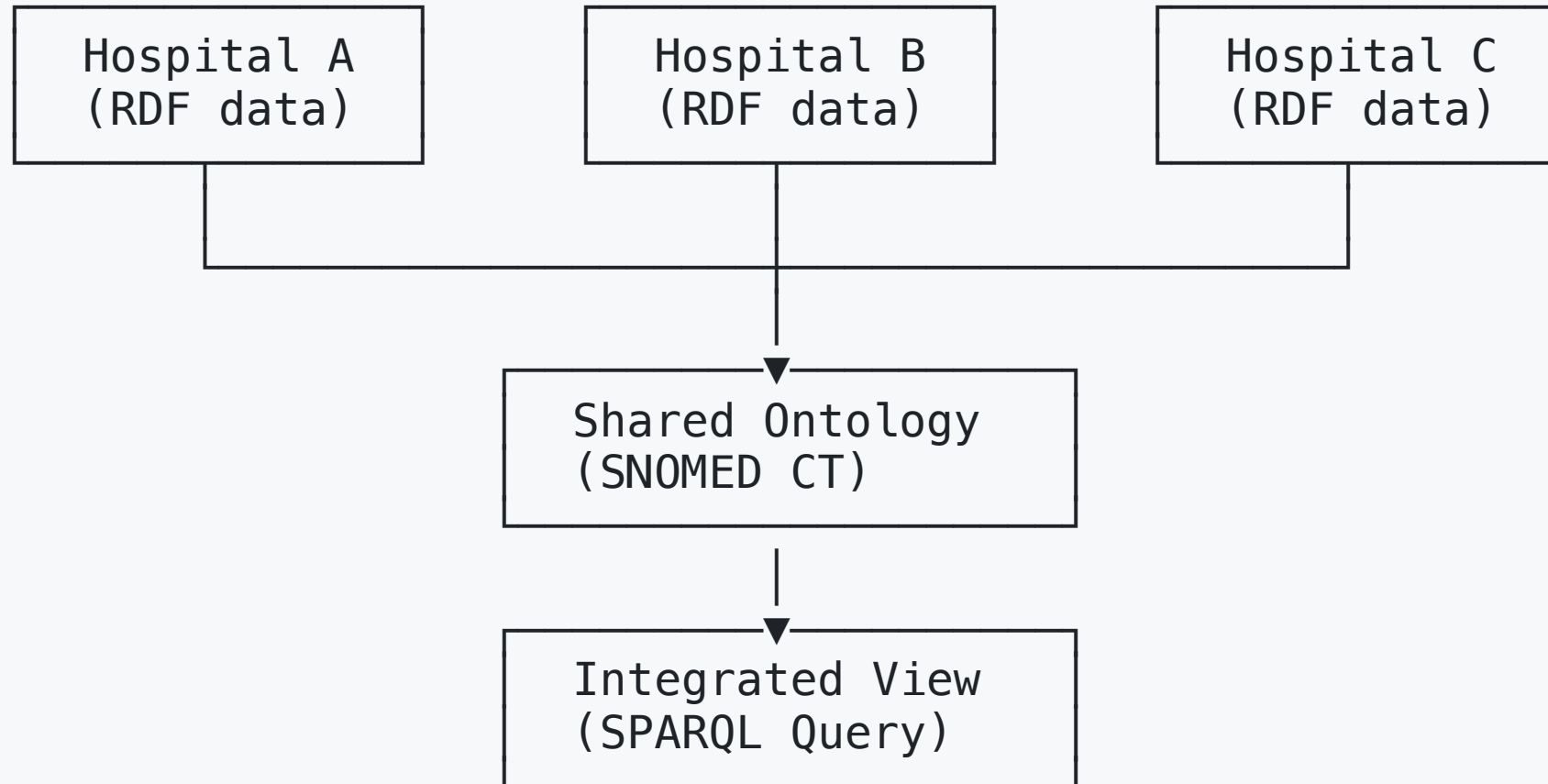
→ Hard to integrate!

With Semantic Web standards:

```
Everyone uses: foaf:firstName  
(Friend of a Friend vocabulary)
```

→ Easy to integrate!

Semantic Web Enables Integration



Putting It All Together

Example: Medical Domain

Layer 3: Semantic Web (Standards)

W3C says: Use RDF for data, OWL for ontology, SPARQL for queries

Layer 2: Ontology (Schema)

```
:Patient rdf:type owl:Class .  
:hasDiagnosis rdfs:domain :Patient ;  
               rdfs:range :Disease .
```

Layer 1: Knowledge Graph (Data)

```
:JohnDoe rdf:type :Patient .  
:JohnDoe :hasDiagnosis :Diabetes .  
:JohnDoe :prescribedMedication :Insulin .
```

Another Example: E-commerce

Layer 3: Semantic Web

- Use schema.org vocabulary
- Use RDF for product descriptions
- Enable cross-site comparison

Layer 2: Ontology

```
:Product rdf:type owl:Class .  
:hasPrice rdfs:domain :Product ; rdfs:range xsd:decimal .
```

Layer 1: Knowledge Graph

```
:iPhone15Pro rdf:type :Product .  
:iPhone15Pro :hasPrice 999.99 .  
:iPhone15Pro :manufacturer :Apple .
```

Relationship Between Layers

```
Semantic Web
  ↓ provides standards for
Ontology
  ↓ defines structure for
Knowledge Graph

Knowledge Graph
  ↑ conforms to
Ontology
  ↑ uses standards from
Semantic Web
```

Bottom-up: Data uses structure uses standards

Top-down: Standards define structure define data

Practical Perspective

When building a system:

1. Choose Semantic Web standards (decide on technologies)

- "We'll use RDF and SPARQL"

2. Create/use Ontology (define your domain)

- "We need Person, Product, Order classes"

3. Populate Knowledge Graph (add real data)

- "Alice bought Product #123 on 2024-01-15"

Bottom-up in practice, top-down in design

Common Confusion 1

"Is knowledge graph part of ontology?"

✗ No!

- Ontology = Schema (the rules)
- Knowledge graph = Data (the facts)

Analogy:

- Ontology = Database schema
- Knowledge graph = Database records

Common Confusion 2

"Is ontology the same as semantic web?"

✗ No!

- Semantic web = Vision + Standards
- Ontology = One technology within semantic web

Analogy:

- Semantic web = The Internet (infrastructure)
- Ontology = HTTP (one protocol)

Common Confusion 3

"Can I have knowledge graph without ontology?"

✓ Technically yes, but not recommended!

Without ontology:

```
:Alice :foo :Bob .  
:Bob :bar 25 .
```

What does this mean? No structure!

With ontology:

```
:Alice :friendOf :Bob .  
:Bob :age 25 .
```

Structure gives meaning!

With Ontology + Explicit Types (Best Practice)

```
:Alice rdf:type :Person .  
:Bob rdf:type :Person .  
  
:Alice :friendOf :Bob .  
:Bob :age "25"^^xsd:integer .
```

We use 'a' as shorthand for 'rdf:type' to explicitly state the types of Alice and Bob.

```
:Bob a :Person ;  
    :age "25"^^xsd:integer .
```


Complete Example

```
@prefix :      <http://example.org/> .
@prefix rdf:   <http://www.w3.org/1999/02/22-rdf-syntax-ns#> .
@prefix rdfs:  <http://www.w3.org/2000/01/rdf-schema#> .
@prefix xsd:   <http://www.w3.org/2001/XMLSchema#> .

### Class
:Person a rdfs:Class .

### Properties (ontology part)
:friendOf a rdf:Property ;
    rdfs:domain :Person ;
    rdfs:range  :Person .

:age a rdf:Property ;
    rdfs:domain :Person ;
    rdfs:range  xsd:integer .

### Data (facts)
:Alice a :Person ;
    :friendOf :Bob .

:Bob a :Person ;
    :age "25"^^xsd:integer .
```

Real-World Examples

Google Knowledge Graph:

- Built on Semantic Web principles
- Uses extensively ontology (schema.org)
- Contains billions of facts (knowledge graph)

Wikidata:

- Uses semantic web standards (RDF, URIs, and SPARRQL)
- Has Wikidata ontology
- Contains millions of entities

Facebook Social Graph:

- Uses semantic web principles
- Has social ontology (Person, Post, Like)
- Contains user data

Different Perspectives

From a researcher's view:

- Semantic Web = Research area
- Ontology = Formal representation
- Knowledge Graph = Application

From a developer's view:

- Semantic Web = Technology stack
- Ontology = Schema definition
- Knowledge Graph = Database

From a business view:

- Semantic Web = Standards compliance

When Do You Use Which Term?

"We're building a knowledge graph"

→ Talking about storing and querying data

"We're designing an ontology"

→ Talking about modeling domain concepts

"We're using semantic web technologies"

→ Talking about RDF, OWL, SPARQL, etc.

"We're creating a semantic web application"

→ Talking about linked open data

Size Comparison

Typical sizes:

Ontology:

- 10-1000 classes
- 50-5000 properties
- Dozens of rules
- KB in size

Knowledge Graph:

- Millions of entities
- Billions of relationships
- TB-PB in size

Evolution Speed

Semantic Web Standards:

- └ RDF (1999) → Still used
- └ OWL (2004) → Still used
- └ SPARQL (2008) → Still used
(Evolve slowly, stable)

Ontology:

- └ Version 1.0 (2020)
- └ Version 1.1 (2021) → Added classes
- └ Version 1.2 (2022) → Modified rules
- └ Version 2.0 (2023) → Major revision
(Evolve with domain changes)

Knowledge Graph:

- └ 2024-01-01: 1M entities
- └ 2024-02-01: 1.2M entities
- └ 2024-03-01: 1.5M entities
- └ 2024-04-01: 2M entities
(Grows continuously)

Dependency Direction

```
Semantic Web (Independent)
  ↓ used by
Ontology (Depends on Semantic Web)
  ↓ defines
Knowledge Graph (Depends on Ontology)
```

You can't have knowledge graph without ontology

You can't have ontology without semantic web standards

Well, technically you can, but it defeats the purpose!

Practical Decision Guide

Question: "What am I working on?"

Adding new facts?

→ Working on Knowledge Graph

Defining new concepts?

→ Working on Ontology

Choosing technologies?

→ Working with Semantic Web standards

Connecting different systems?

→ Using Semantic Web principles

Summary Table

| Layer | What | Example | Purpose | Size |
|-----------------|-----------|--------------|------------------|----------------|
| Semantic Web | Standards | RDF, OWL | Interoperability | Standards docs |
| Ontology | Schema | Person, Food | Structure | 100s classes |
| Knowledge Graph | Data | Alice, Pizza | Facts | Millions |

Semantic Web (Independent)

↓ used by

Ontology (Depends on Semantic Web)

↓ defines

Knowledge Graph (Depends on Ontology)

```
**You can't have knowledge graph without ontology**  
**You can't have ontology without semantic web standards**  
*Well, technically you can, but it defeats the purpose!*
```

```
---
```

```
## Practical Decision Guide
```

Key Takeaways

- ✓ Three distinct layers with clear purposes
- ✓ Semantic Web = Standards and vision
- ✓ Ontology = Schema and rules
- ✓ Knowledge Graph = Data and facts
- ✓ They work together, not separately
- ✓ Each layer depends on the one above

Understanding the layers helps you talk about and build better systems!

Common Mistakes to Avoid

✗ "Let's build an ontology" (when you mean knowledge graph)

✓ "Let's populate our knowledge graph"

✗ "Our semantic web contains customer data"

✓ "Our knowledge graph contains customer data"

✗ "The ontology has 1 million products"

✓ "The knowledge graph has 1 million products"

✗ "We're designing the knowledge graph"

✓ "We're designing the ontology"

Questions to Test Understanding

Q1: "We added 10,000 new customers to the system"

→ Which layer? **Knowledge Graph**

Q2: "We defined what a Customer is"

→ Which layer? **Ontology**

Q3: "We decided to use RDF instead of JSON"

→ Which layer? **Semantic Web**

Q4: "Two companies want to share data"

→ Which layer helps? **Semantic Web (standards)**

Next Steps

In upcoming lectures:

1. Deep dive into RDF and triples (Semantic Web layer)
2. Building ontologies with Protégé (Ontology layer)
3. Creating and querying knowledge graphs (KG layer)
4. Integration patterns (using all three)

Now you have the foundation to understand where each piece fits!