# Extensible Modeling Languages

## Utilizing Libraries for Model Creation, Use, and Domain-Specific Extensions

**5th MODPROD Workshop on Model-Based Product Development**

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## Equation-Based Object-Oriented (EOO) Languages



**Domain-Specific Language (DSL)**

- **Primarily domain:** Modeling of physical systems
- **Multiple physical domains:** e.g., mechanical, electrical, hydraulic

- **Modelica**
- **VHDL-AMS**
- **gPROMS**

**Models and Objects**

- **Object in e.g., Java, C++:** object = data + methods
- **Objects in EOO languages:** object = data + equations

**Equation-Based Object-Oriented (EOO)**

**Acausality**

- **At the equation-level**
  u = R * i
- **At the object connection level**

# Agenda

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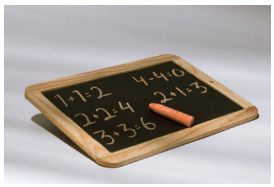
**Part I**
**Expressiveness**

**Part II**
**Extensibility**

**Part III**
**Formalization**







# Expressiveness

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**Expressiveness – ease and possibility of expressing complex models or tasks**

**Language versions:** A, v1.0 → A, v1.1 → A, v2.0 → A, v2.2

**Standard library versions:** L, v1.0 → L, v1.1 → L, v2.0 → L, v2.2

# Extensibility

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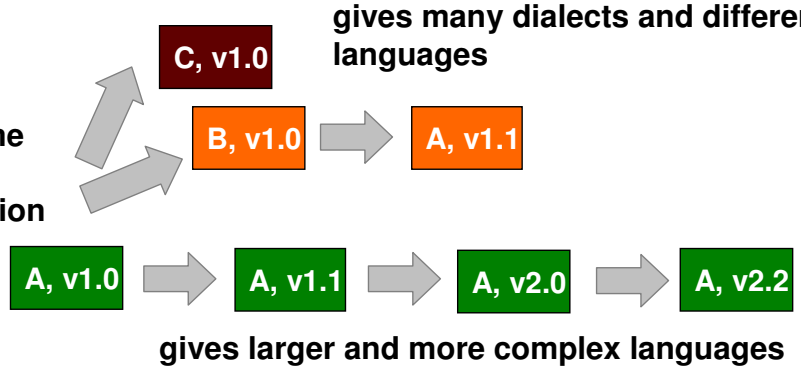
## Extensibility – mechanisms to add new language features

**Uses**

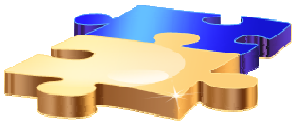
- Simulation
- Optimization
- Code generation for real-time
- Model export
- Grey-box system identification

etc.




gives many dialects and different languages

gives larger and more complex languages







# Formalization

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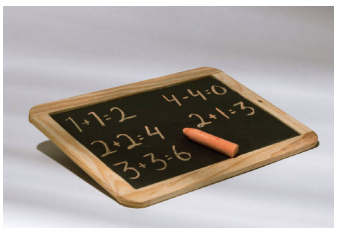
## Formalization – precise semantics "meaning" of the language

**Language Specifications of state-of-the-art are informally defined**

- hard to interpret unambiguously when developing compilers
- hard to reason about when extending the language
- hard to formalize e.g. Modelica due to size and complexity



# What is MKL?

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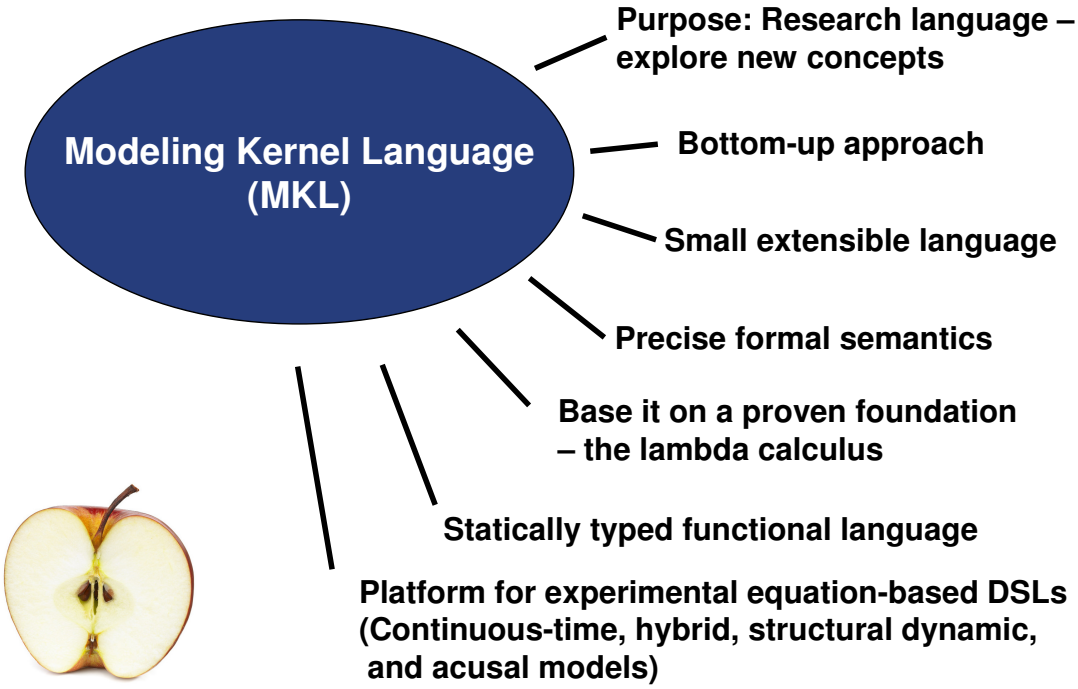








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# Part I

## Expressiveness

# Expressiveness - HOAM

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## Higher-Order Acusal Models (HOAM)

**Higher-Order Functions**
I.e. first class citizens, can be passed around as any value

+

**Acausal Models**
Models in EOO languages, composing DAEs and other interconnected models.

=

**Higher-Order Acausal Models**
I.e., first class acausal models.





# HOAM – Example

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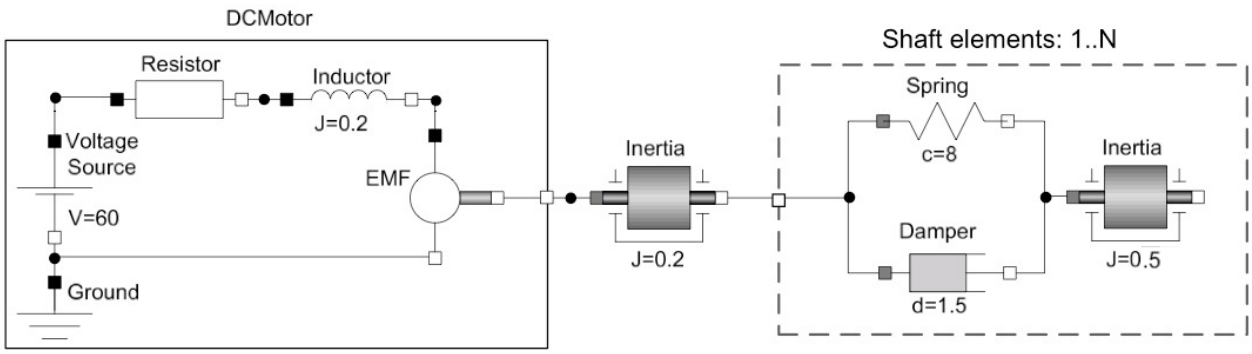
**Example of a mechatronic system with a DC motor and a flexible shaft**




```
let ShaftElement flangeA:Rotational -> flangeB:Rotational ->
                 Equations =
  let r1:Rotational in
  Spring 8. flangeA r1;
  Damper 1.5 flangeA r1;
  Inertia 0.5 r1 flangeB
```

**One shaft element is created by standard components.**

# HOAM – Example

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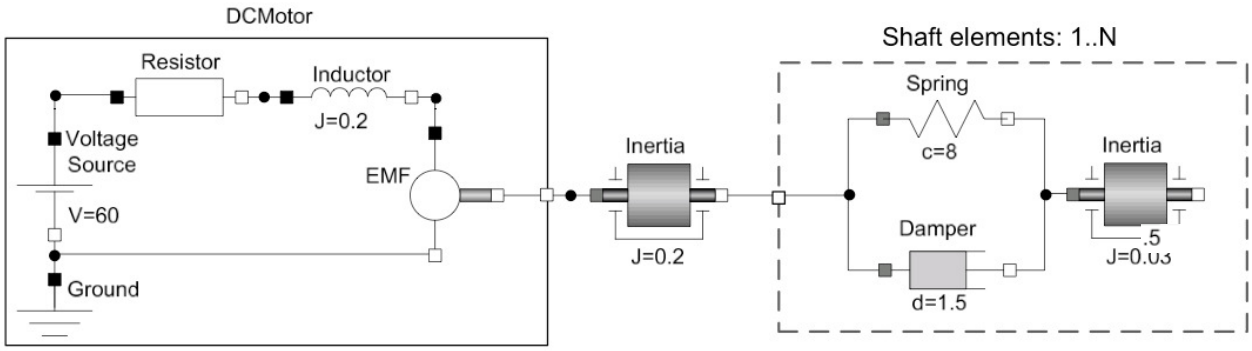
**Example of a mechatronic system with a DC motor and a flexible shaft**




```
let MechSys =
  let r1:Rotational in
  let r2:Rotational in
  let r3:Rotational in
  DCMotor r1;
  Inertia 0.2 r1 r2;
  (serializeRotational 120 ShaftElement) r2 r3
```

**Higher-order function that can compose any mechanical component in series**





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# Part II

## Extensibility

# Modelica Environment

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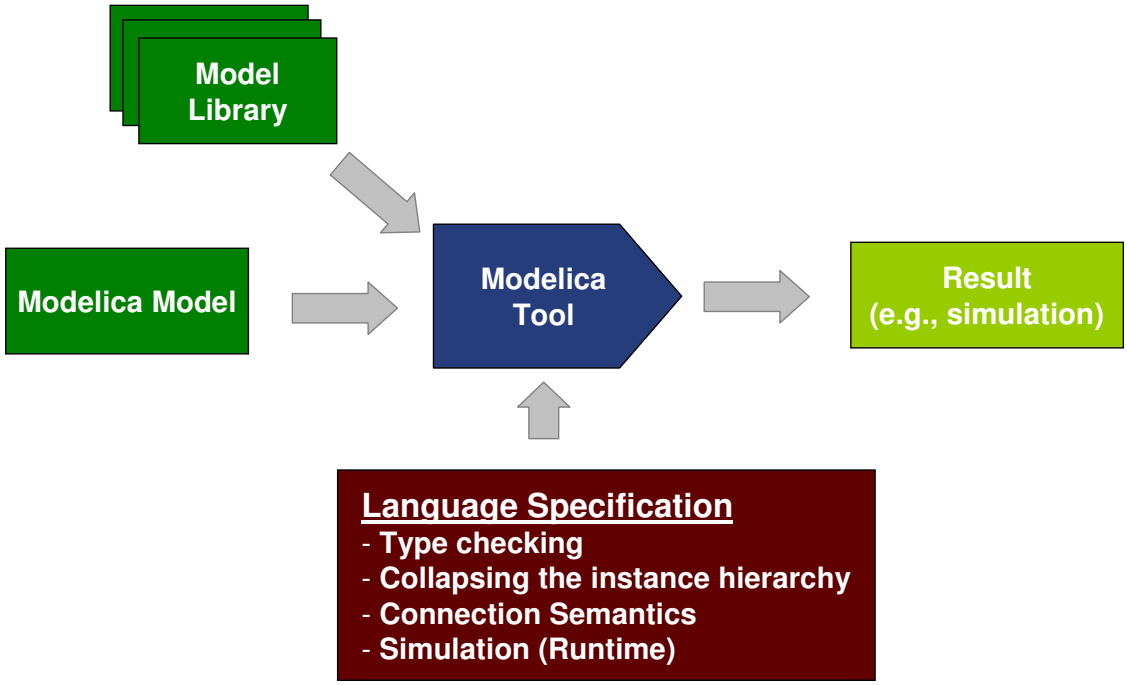






# MKL Environment

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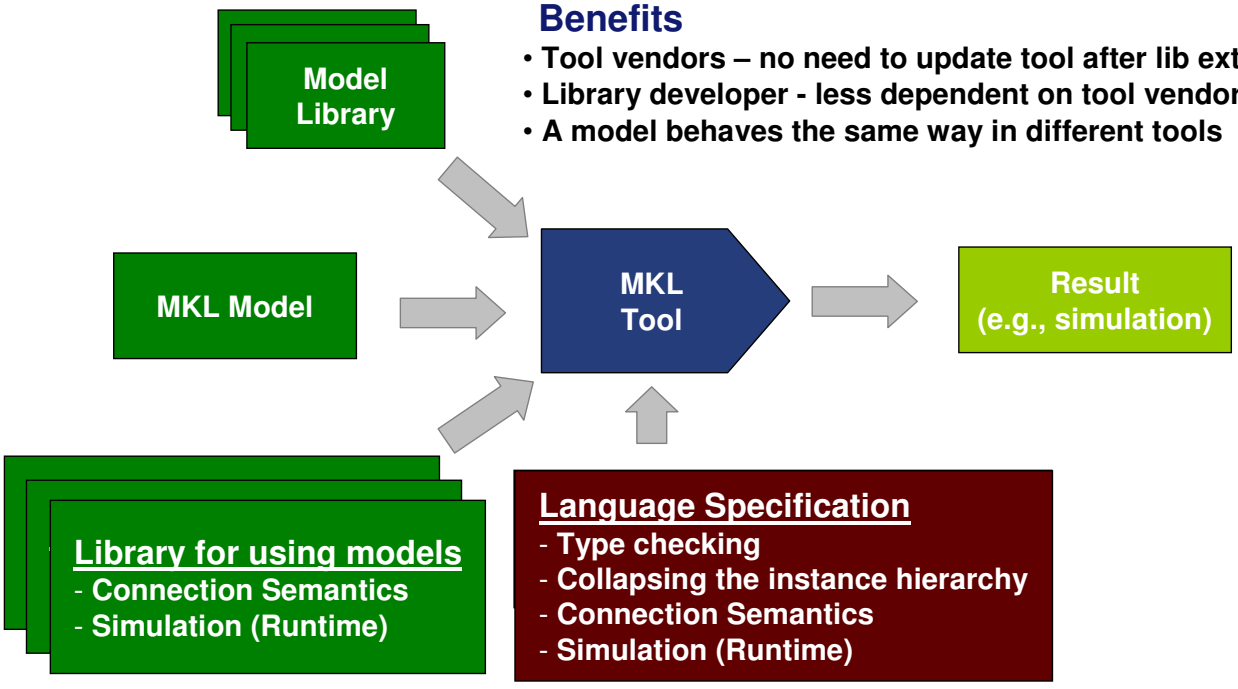

# Intensional Analysis and Model Lifting

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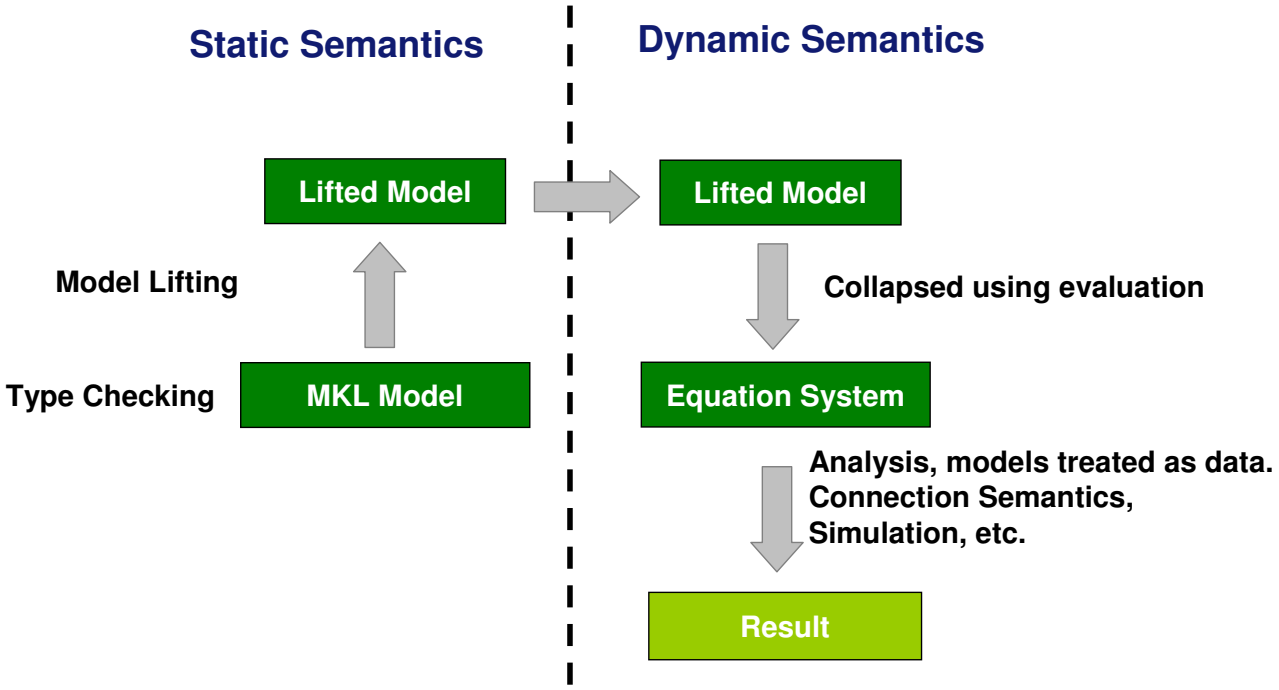






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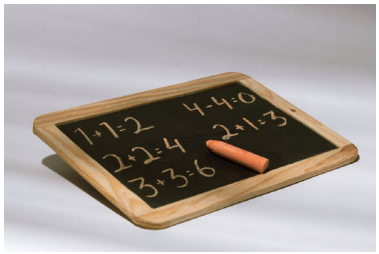
# Part III

## Formalization



# Formalization of Semantics

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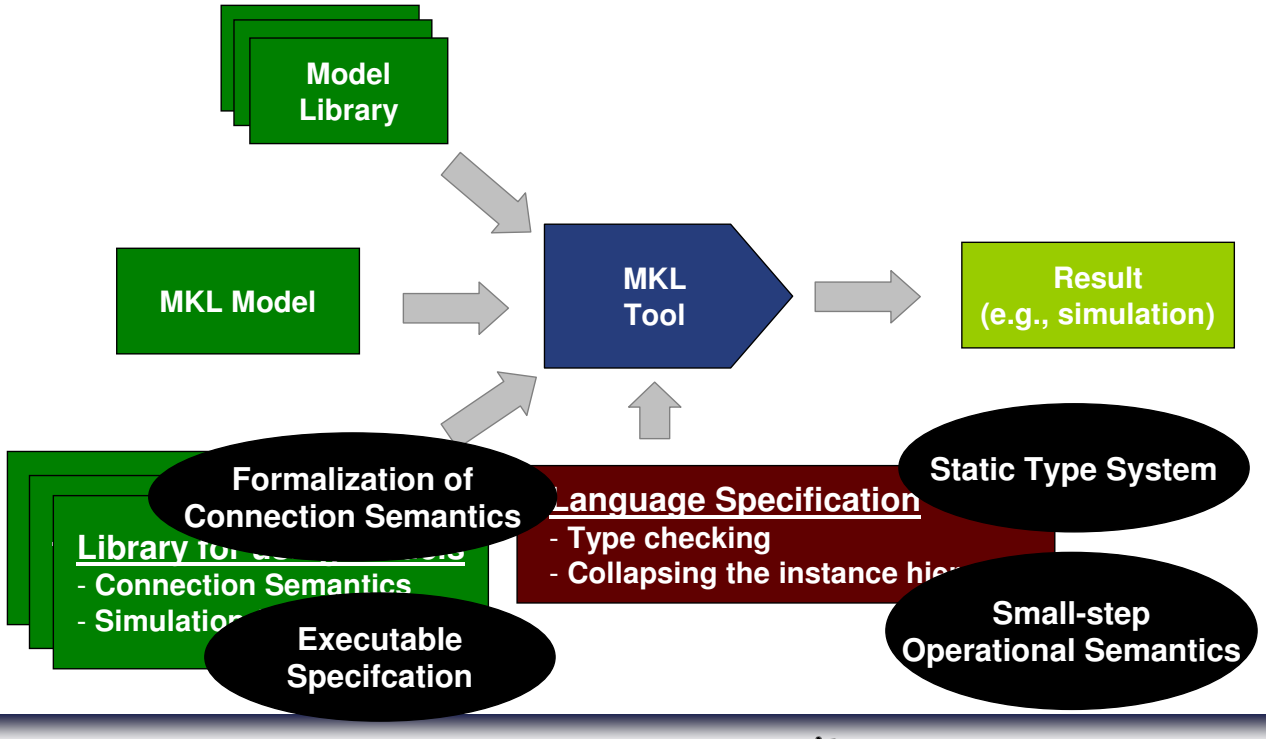






# How do we verify our solution?

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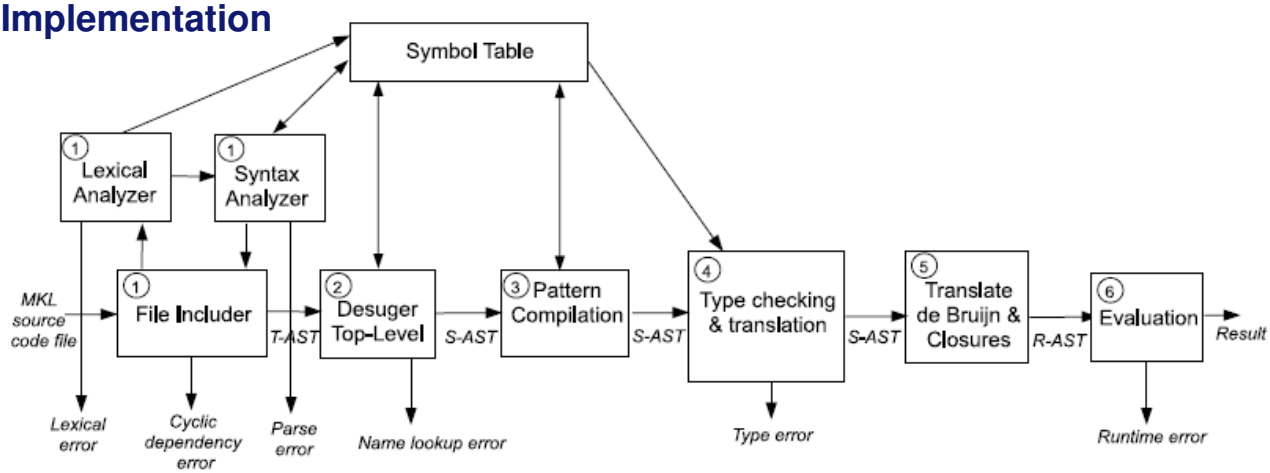
## Prototype Implementation




## Type Safety Proof

**Two main lemmas**

- **Progress**
- **Preservation**

# Conclusions

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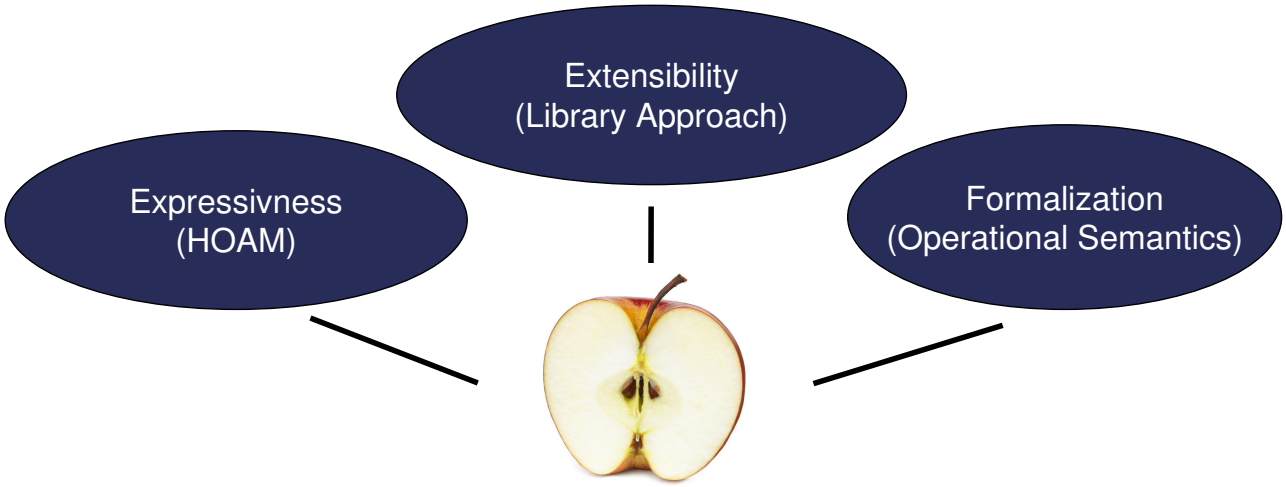


**Modeling Kernel Language (MKL)**

## Thanks for listening!