Device ontology
An enabling technology for consistent modeling of physical systems

Riichiro Mizoguchi
JAIST
(Japan Advanced Institute of Science and Technology)
Agenda

- Modeling in Engineering

- What is Device ontology and why do we need it?
  - Underlying philosophy
  - The key concept with examples

- Applications
  - Function definition
    - Artifact functions and Biological functions
  - Function decomposition
  - etc.
Modeling the targets

- Quantitative VS. Qualitative models
- Domain ontology
- How to **capture essentials** of the domain in a **domain-independent** manner
Capturing essentials

- **Domain-specific terms/concepts**
  - Fine-grained and expert-friendly
  - Small generality with large specificity
  - Hard to capture essentials

- **Domain-independent terms/concepts**
  - Coarse-grained and abstract
  - Large generality with less specificity
  - Sometimes too general to be useful

- **Another way of abstraction/generalization??**
  - Moderate generality with links to domain specificity
**Device ontology**

- **Basic elements**
  - **Device**
    - It receives input, operates on it, and outputs it
    - Black box assumption
  - **Connection**
    - A device has Input/output ports and connected with one another
  - **Conduit** = Semi-device
    - Ideally, it can be considered that it changes only location of the input to output.
      E.g., pipe, wire
Extended device ontology

- **Major elements**
  - **Device** (*agent*)
    - It processes the flowing thing (*operand*). Black box assumption
  - **Conduit** = Semi-device
    - Ideally, it can be considered that it changes only location of the flowing thing.
      E.g., pipe and shaft
  - **Operand** (which is processed by the *device*)
    - It flows through devices
    - The change of its state is interpreted as the behavior of the device.
      E.g., energy, fluid, motion & force, information
  - **Medium**
    - It keeps/carryes *operand* to enable it to flow
      E.g., fluid (carrying heat) and shaft (carrying torque)
    - It flows, but not always (case by case)
  - **Connection, Input/output**
Roles

- A role is a dependent entity played by an entity in a context
  - Teacher in a school context, wife/husband in a marriage context
- Any object and occurrent can be a context of a role
  - Part role (teacher) and participant role (singer, destination)
- An entity becomes a role-holder when playing a role
  - A role-holder inherits properties inhering in the role by playing it
  - So, the player and the role-holder are different entities
  - Domain entities are potential players for a role(s)
  - Depending on the context, an entity can play multiple roles
Device ontology is a Role assignment system in modeling phenomena in reality

- The world is full of **Roles** depending on contexts
- **Role vs. Players** (domain entities)
- We need a guiding principle to enable us consistent interpretation of the domain/target domain-independently
- **Device ontology is a candidate**
Examples

- In the power plant domain (e.g., a pipe, a boiler)
  - A pipe plays a **conduit role** to allow the water/steam to flow
  - Heat energy plays an **operand role**, and is
  - carried by the flowing water/steam which plays the **medium role**
  - The **medium** (liquid) flows through the devices/conduits

- In the mechanical engineering (e.g., a transmission)
  - A shaft plays a **conduit role**
  - Torque plays the **operand role**, and is
  - carried by a rotating shaft which allows torque to flow.
  - A shaft plays the **medium and conduit roles**
  - The **medium** (shaft) does NOT flow
Two use contexts

- Used as a component in a system
  - Imagine a pump
  - Who uses it?

Systemic context

- Used as a tool
  - Hammer or screwdriver
  - A human *uses* it
The hammer case

- **Hand**: Surrounding force
- **Grip**: To fix
- **Bar**: Small motion, To amplify
- **Head**: Big motion, Vertical Impact, To hit
Another case

Gravity

Downward force

Upward force

Light

Letters
Any phenomena can be interpreted as a behavior of a system composed of multiple components/parts/features.

A device is a role played by an object/system whose behavior is defined as a pair of input and output.

A pair of Input and output of a device is determined according to the context set by the modeler.

Any object can be interpreted as playing a device role by identifying behaviors of interest.

Any device is a black box at a level of the granularity and hence you are not allowed to look into inside to know how the behavior is realized at the level of granularity.

Any device except at the least granularity level is composed of finer-grained devices connected each other, that is, a device is modeled in a nested structure in device ontology.

Every pair of role and role player keeps links between domain entity and role.

This guarantees consistent modeling in a domain-independent framework.
Applications
Four kinds of behavior

B0: the temperature increases
B1: A heater heats the water
B2: Moving air by rotation
B3: A cam pushes up a rod
Basic characteristics of function

- **Context-dependence**
  - Systemic context
    - *Internal*/parts’ goal
    - *External* goal (teleological context)

- **Implementation-independent**
  - Black box

- **Composability**
  - Localization is a key
  - So, to cool is not a function of an electric fan
A function performed by a device is a role played by the behavior of the device to achieve a specific goal under a systemic context (including context of use), based on a certain capacity inherent in the device.

Role is context-dependent entity defined with external entities.

- Our theory of role [Mozoguchi 00, 06, 15].
- Founded (i.e., extrinsic property essentially dependent on an external entity)
  - Function of a device refers to the systemic context.
- Anti-rigid (i.e., contingent (non-essential) property)
  - The role isn’t essential to the behavior, it loses the role in a different context
- Dynamic (i.e., temporary and multiple)
  - A behavior can play multiple roles and the role can be played by different behaviors.
Functional ontology

- Functional concepts
- Meta-function, Function type
- Function achievement way
- Functional decomposition
Distinction between F and B

Behavior of a device
- Temporal changes of physical quantities of operands as input and output of the device
- Independent of the context

Function of a device
- Dependent on “systemic context”
  - A behavior can perform different functions under different contexts.
  - Systemic context (a system configuration)
    - External context (direct user’s purpose)
- A function can be performed by different behaviors and agents.
- Function is defined as a “role” played by a behavior under a systemic context
Reference ontology of function

requirement function

system boundary function
genuine effect function.
state-operational function
(normal)function

device function
way function
process-operational function
inter-device function

environmental function
physical environmental function

meta function

user action enabling function
environmental interpretive function

characteristic function
disposition function

effect function.

property function

function

Legend:

is-a
Another way of capturing essentials
Functional decomposition

Two kinds of decomposition:
1. In terms of Granularity
2. What to achieve and how to achieve
Examples of decomposition

- **To weld**
  - What to achieve = To *join* sheets of metals
  - How to achieve = By fusion way

- **To glue**
  - What to achieve = To *join* two things
  - How to achieve = By glue way
Filter
- remove coffee powder

Filtering way
- Melior
- move water and coffee powder
- consume movement of coffee powder

Pressure
- High pressure way (espresso)
- Dripping way

Vaporization
- Pressure
- move up water
- control quantity of water
- move down water
Functional concept ontology

# of functional concepts = about 100
Organization of generic ways of function achievement for “splitting”

Ways for “splitting”
- Removing way
  - Lose combination force of a part (the kerf loss)
  - Move the part away
- Breaking way
  - Make stress
  - Breaking by stress

Ways for losing combination force
- Changing way
- Physical force way
  - Exert force
- Chemical way
- Melting way
- Electrolysis way
  - Electrolysis cutting
- Ways for Exerting force
  - Collision way
  - Frictional way
    - Screw-type washing machine
    - Whirlpool friction way
  - Falling way
  - Drum-type washing machine
  - Liner friction way
  - Wire-saw
  - Lateral pressure cutting
  - Tensile stress way
  - Shearing stress way
  - Lateral pressure cutting
  - Tensile stress way
  - Shearing stress way
Detach “how to achieve” from the function
- To weld = to join by fusion way
- A way consists of one principle
Concluding remarks

- Device ontology is a conceptual tool
- It enables you to model dynamic systems domain-independently
- It has contributed to defining function

- We have proposed a theory of Causation
  - Function grounds causation
    - function exists $\iff$ causation exists