

Standardization to Digitalize Control Design and Delivery

Michael Wetter

October 12, 2023

Overview

What problem do we solve?

New ASHRAE Standard 231P “Control Description Language”

Integrating standards for robust control digitalization

Q&A

What problem do we solve?

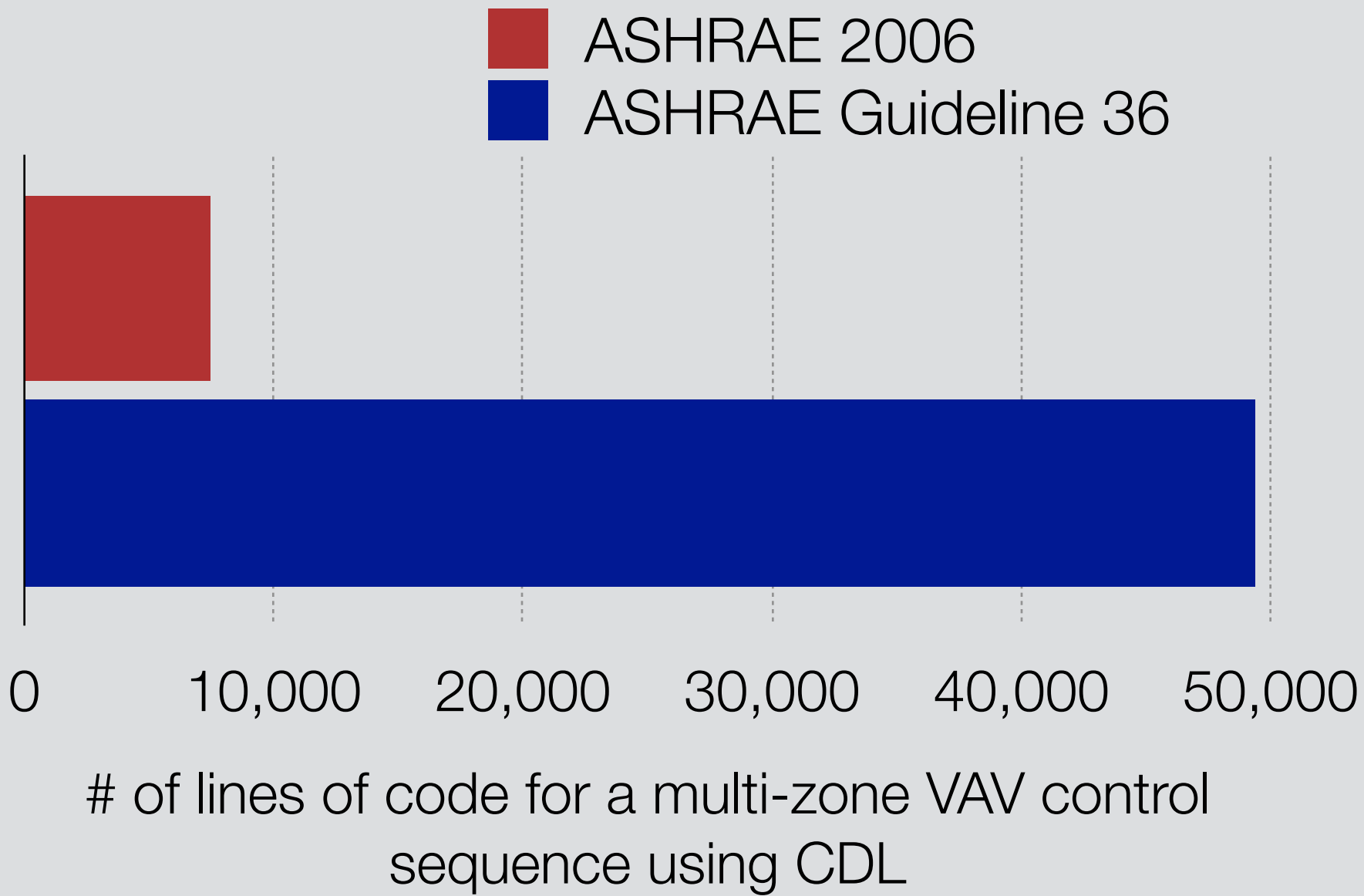
Why do we think we can meet new integration challenges if we even fail to deliver yesterday's energy systems in a robust way?

2000

Human factor	Not-specified	12.0
	Operator indifference	0.0
	Operator interference	10.4
	Operator unawareness	4.2
	Operator error	6.8
Software	Data management	0.3
	Operation system	1.0
	Programming	31.3
	Input/out implementation	2.1
Hardware	Communication	1.6
	Controlled device	12.0
	Controller	2.6
	Input device	15.9

Control-related problems
(Ardehali, Smith 2002).

2020



2030 ?

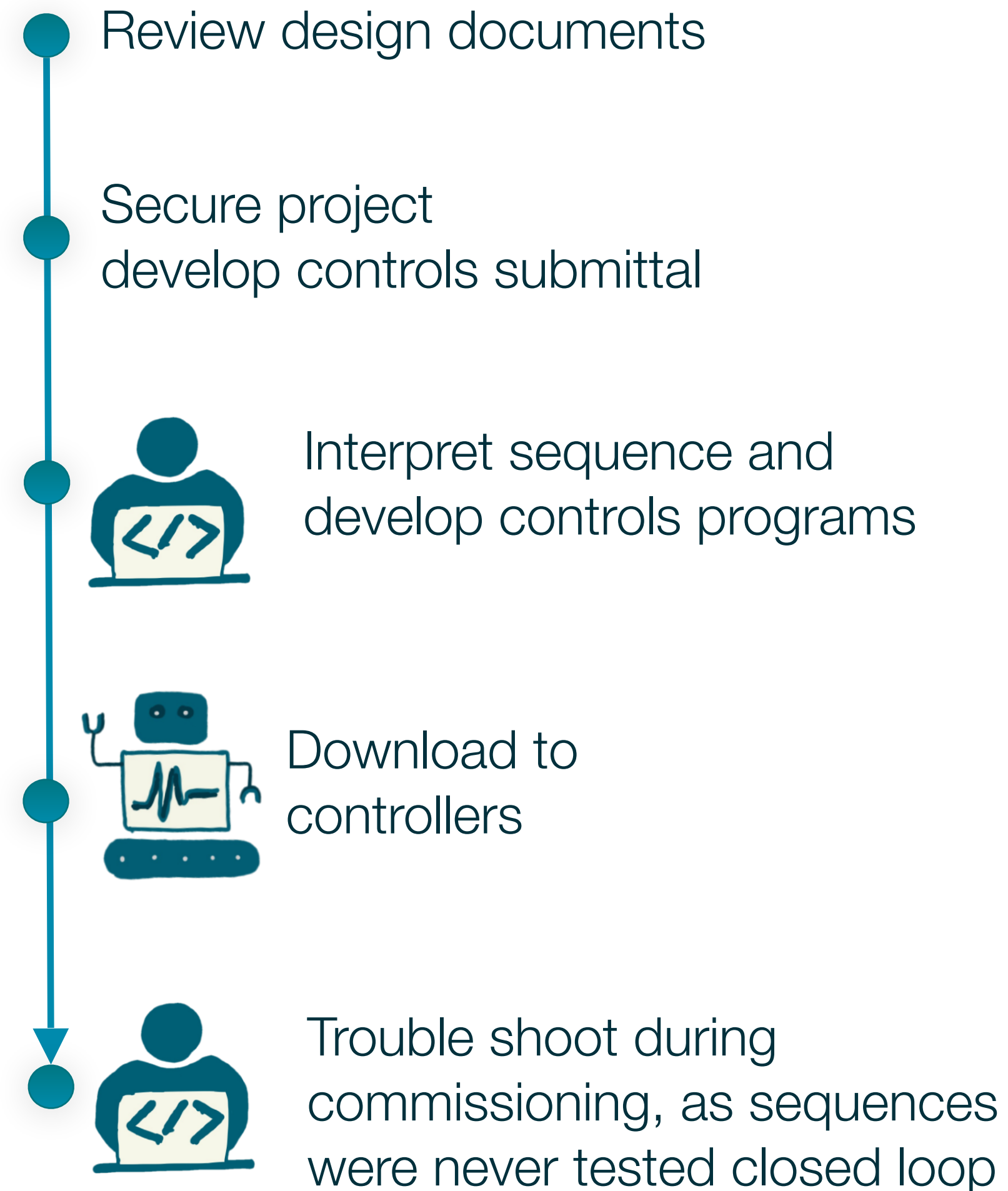
Control optimizes across energy carriers.
Digital twin & real-time data integration.
IoT
...



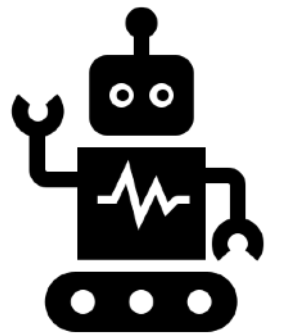
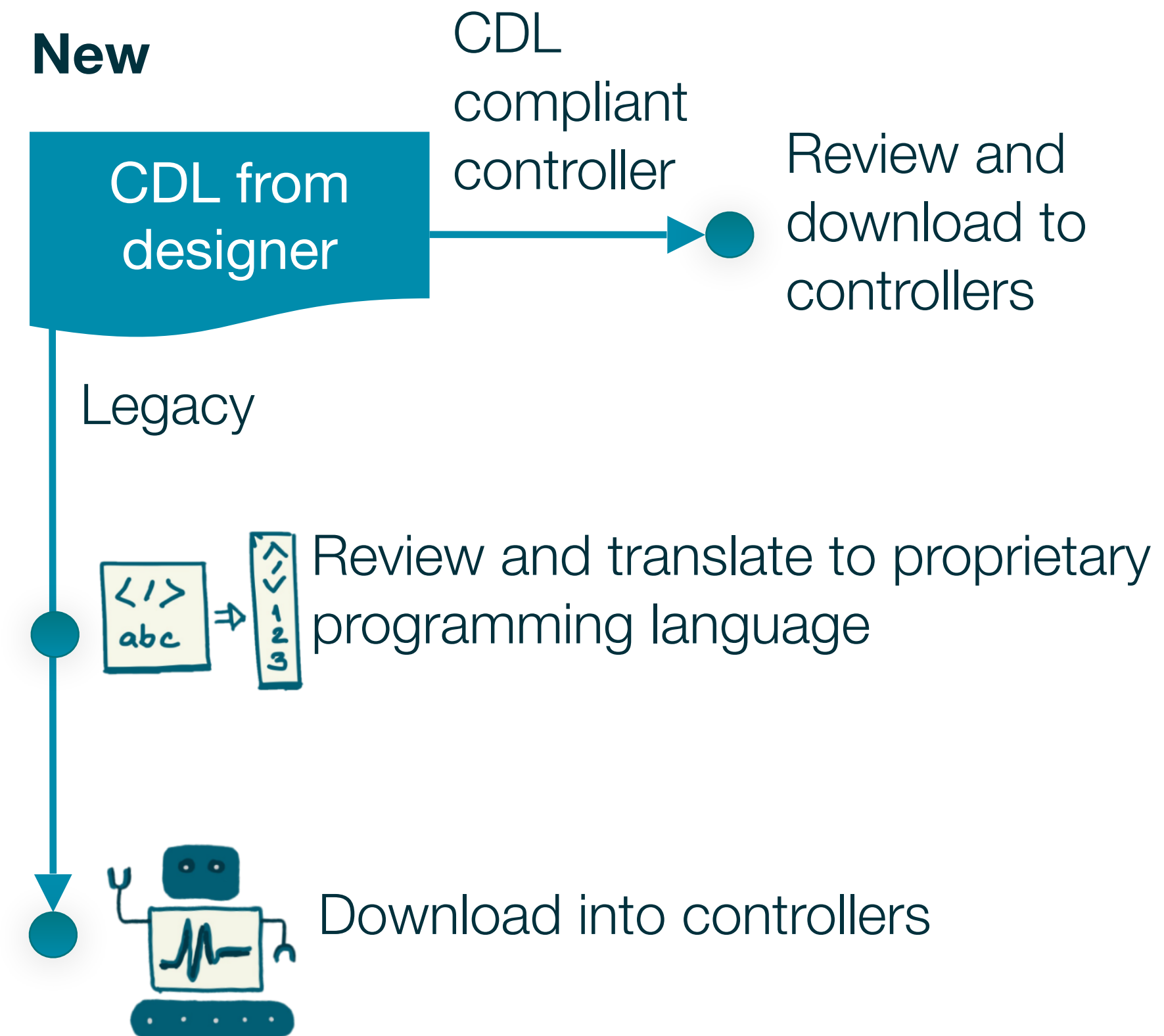
See previous presentation
of David Blum for more
context.

Controls Delivery Process

Conventional



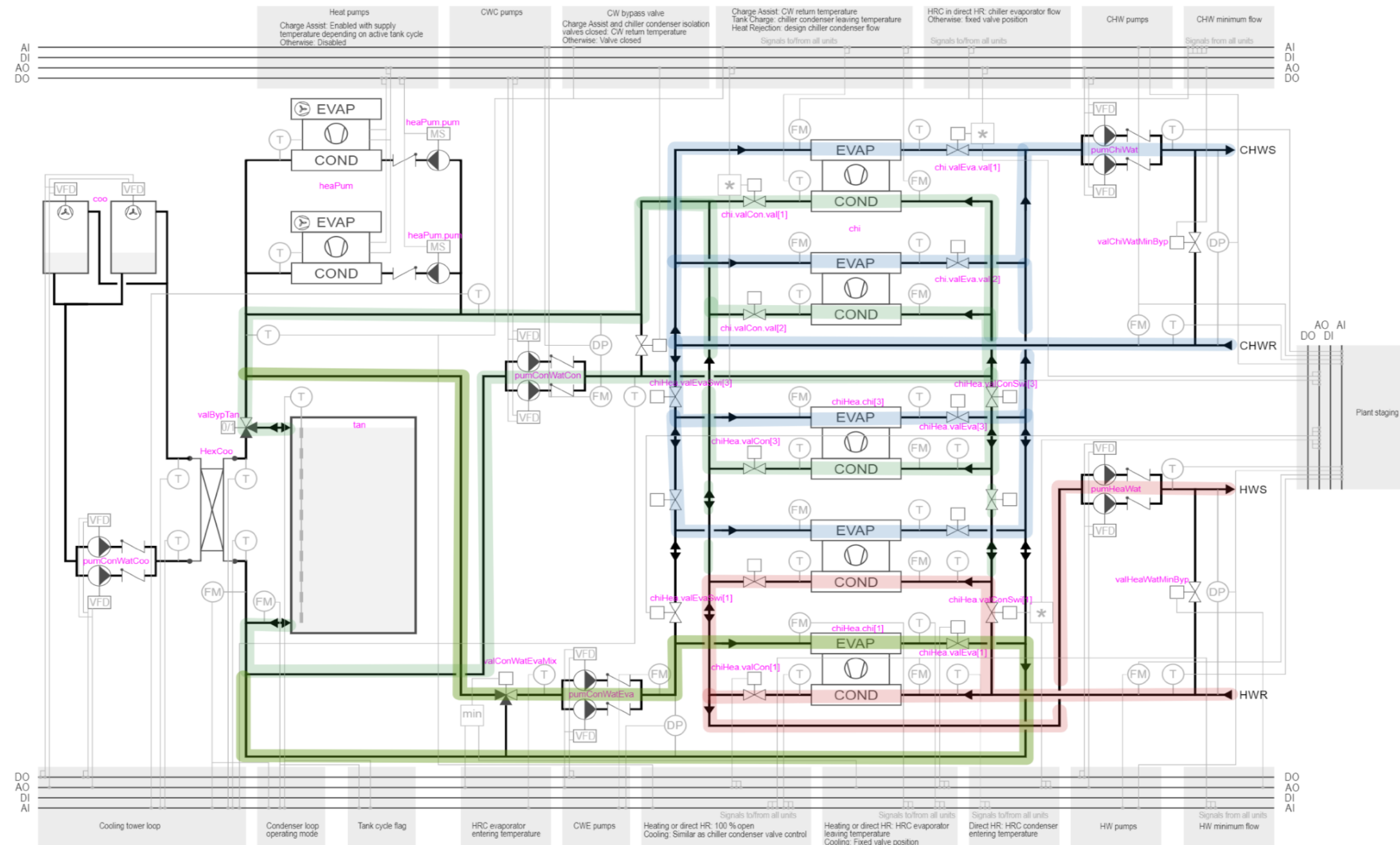
New



Point in case: Heat pump plants

Industry is not ready to deploy complex, untested decarbonized systems – certainly not at scale

High-profile failures (often requiring expensive retrofits) only make the problem worse



HVAC & control complexity

- 20 modes of operation
- multiple heat pumps
- storage with 5 tuning parameters
- multiple cooling towers
- **45 pages of control sequences**

See reports of failed heat pump deployment in Europe.

Cost-effective, high-efficiency HP plant with small footprint needed for dense developments have complexities that stifle large scale deployment

(<https://taylorengineers.com/news-1/new-article-in-the-ashrae-journal>, implementation in

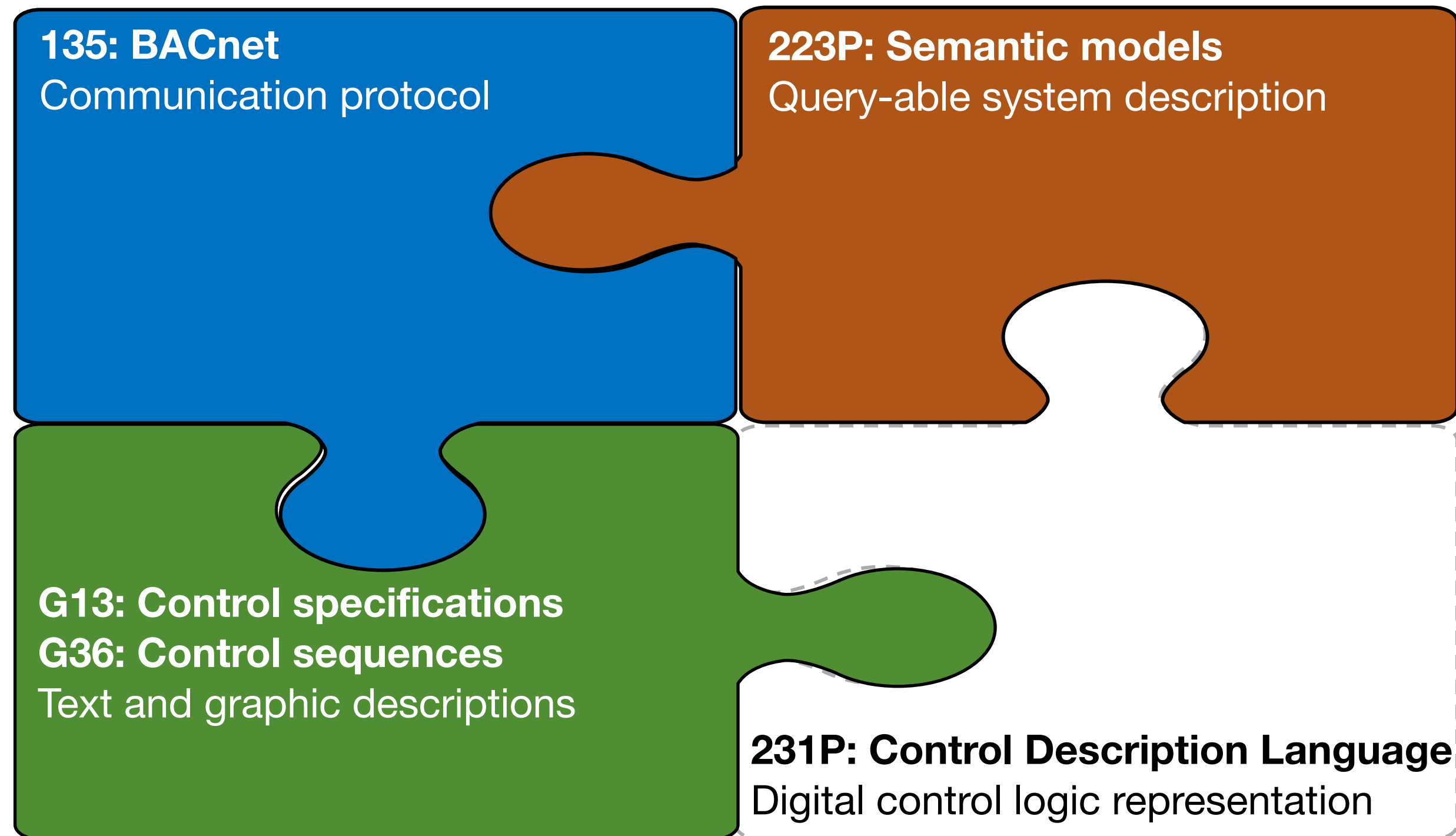
https://simulationresearch.lbl.gov/modelica/releases/v10.0.0/help/Buildings_Experimental_DHC_Plants_Combined.html)

New proposed ASHRAE Standard 231P (draft)

History of CDL/ASHRAE Standard 231P

- **2018:** Michael Wetter, Milica Grahovac and Jianjun Hu.
Control Description Language.
1st American Modelica Conference, Cambridge, MA, USA, August 2018.
- **2020:** ASHRAE approved formation of Standards Committee 231: Control Description Language
- **2022:** Publication of digitizing control delivery.
Michael Wetter, Paul Ehrlich, Antoine Gautier, Milica Grahovac, Philip Haves, Jianjun Hu, Anand Prakash, Dave Robin and Kun Zhang.
OpenBuildingControl: Digitizing the control delivery from building energy modeling to specification, implementation and formal verification.
Energy, Volume 238, Part A, January 2022.
- **2023:** First release of ctrl-flow.lbl.gov, based on Control Description Language.
- **2024:** Expected public release draft of ASHRAE Standard 231P.

ASHRAE Standard 231P fills a gap by creating a digital control logic representation



Requirements for a digital control logic specification

- Deterministic
- Translate-able to physical control platforms
- AND simulate-able \leftarrow must be both in order to bridge BEM and controls

ASHRAE Standard 231P: “Control Description Language (CDL)” \leftarrow a subset of another standard called Modelica.

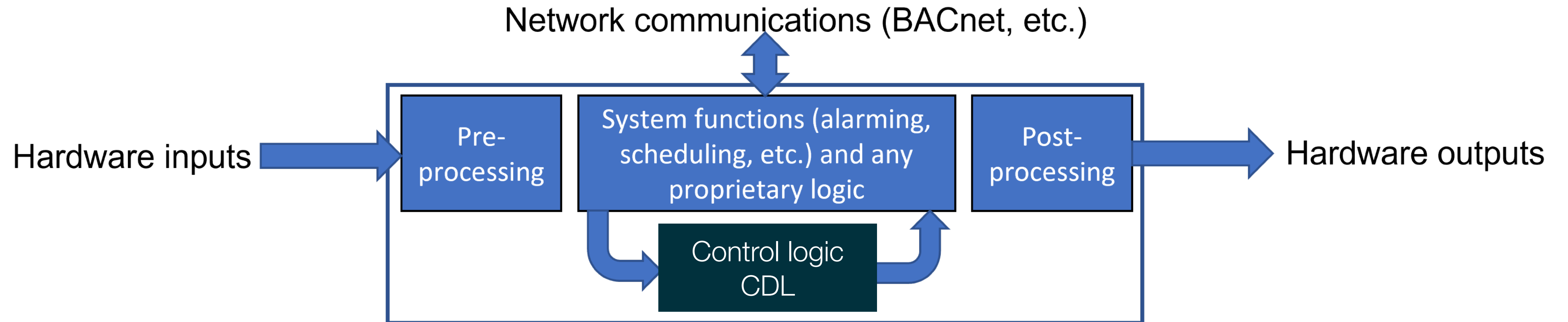
A block diagram for implementing control logic, first described in Wetter et al., 2018.

Michael Wetter, Milica Grahovac and Jianjun Hu.

[Control Description Language](#).

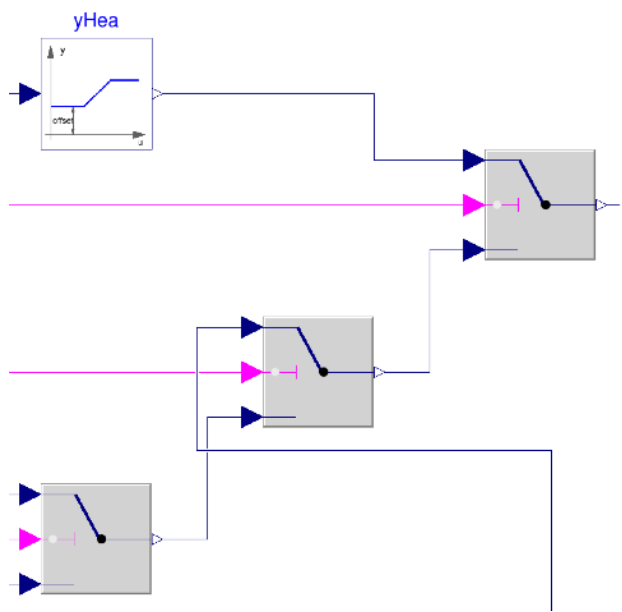
1st American Modelica Conference, Cambridge, MA, USA, August 2018.

What is the scope of CDL?



What is the Control Description Language?

A declarative **block diagram language**.



A **library** about about 150 elementary input/output blocks that should be supported, through a translator, by control providers.

Example:
CDL has a MultiplyByParameter block with input u , gain k , and output $y = k * u$.

CDL

Continuous

Conversions

Discrete

DayType

FirstOrderHold

Sampler

TriggeredMax

TriggeredSampler

UnitDelay

Output the absolute value of the input

Information

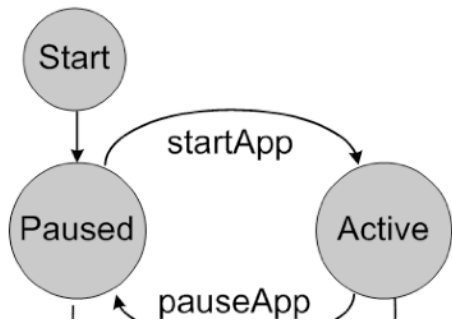
Block that outputs $y = \text{abs}(u)$, where u is an input.

Connectors

Type	Name	Description
input RealInput	u	Connector of Real input signal
output RealOutput	y	Connector of Real output signal

A **documentation syntax** for control blocks and sequences.

A **model of computation** that describes when to update signals.



A language fully compatible with the open Modelica standard, enabling **simulation** and **code generation**.

Basic elementary blocks are defined in a library that is immutable to the users (fixed by the specification).

Behavior is expressed mathematically,

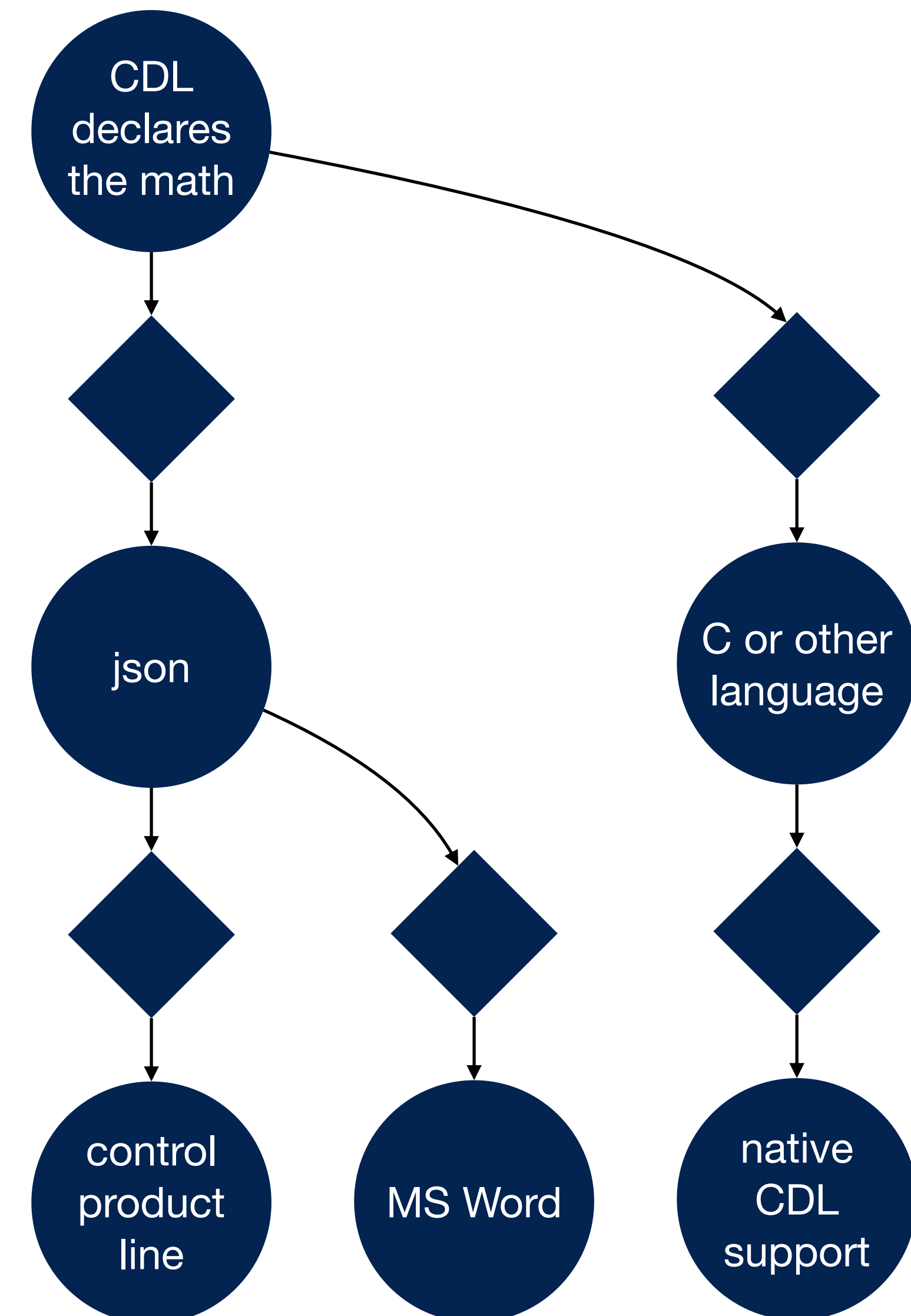
$$(p, t, u(t), x(t)) \mapsto y(t).$$

Software implementation is not part of the specification, as it should not be part of the standard.

Note: This implies that

- the implementation can be graphical or text-based.
- CDL-compliant sequences can be executed as functions (C, Java, Python, Julia, ...)
- The controller product line does not need to know anything about CDL.

Control providers who support CDL need to be able to implement the same functionality as is defined by the elementary CDL blocks.



How we specified CDL

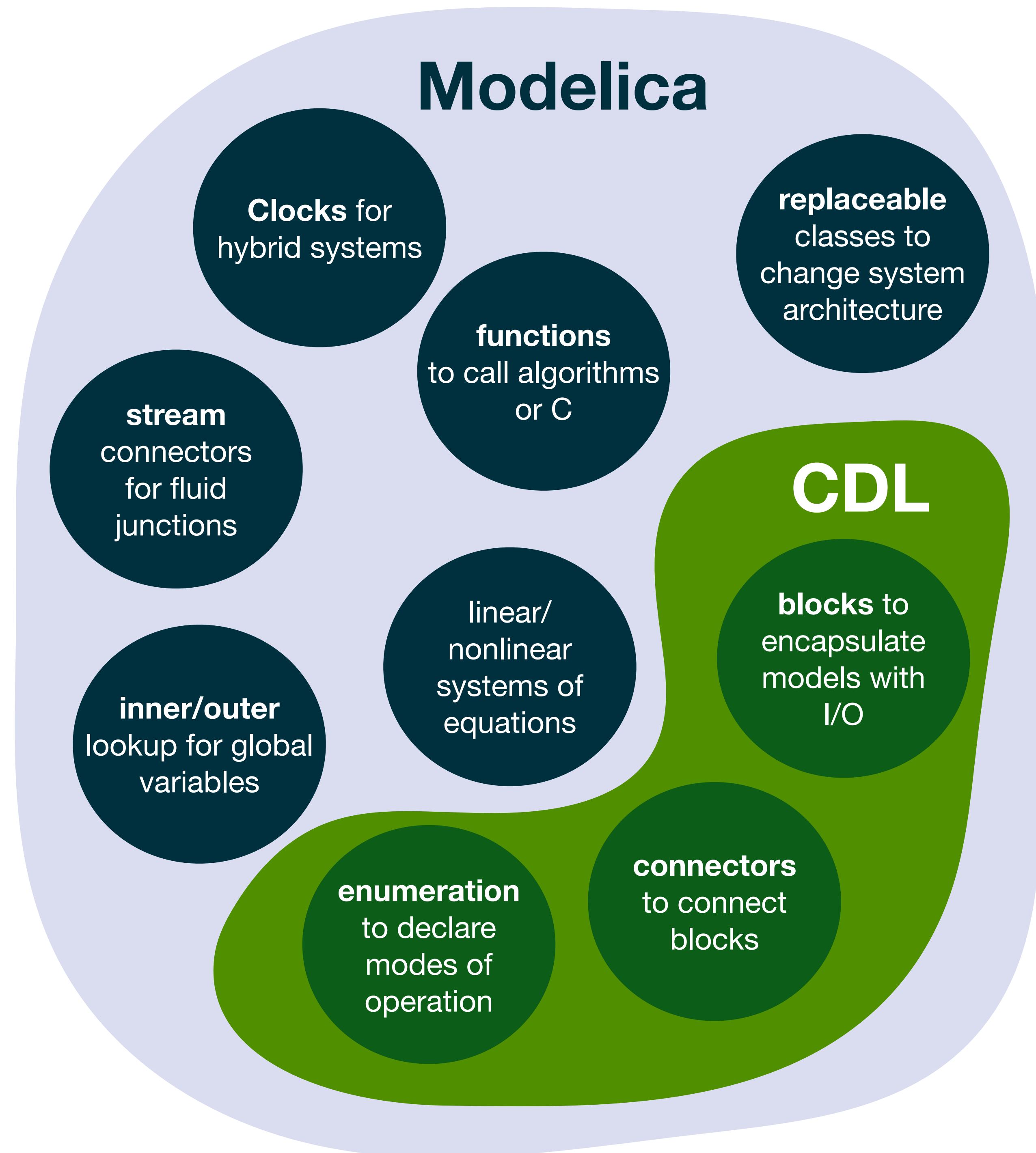
Conform to the Modelica Standard 3.3, **but** remove everything that is not needed to practically declare control logic and their English language documentation.

Keep it simple & easy to parse.

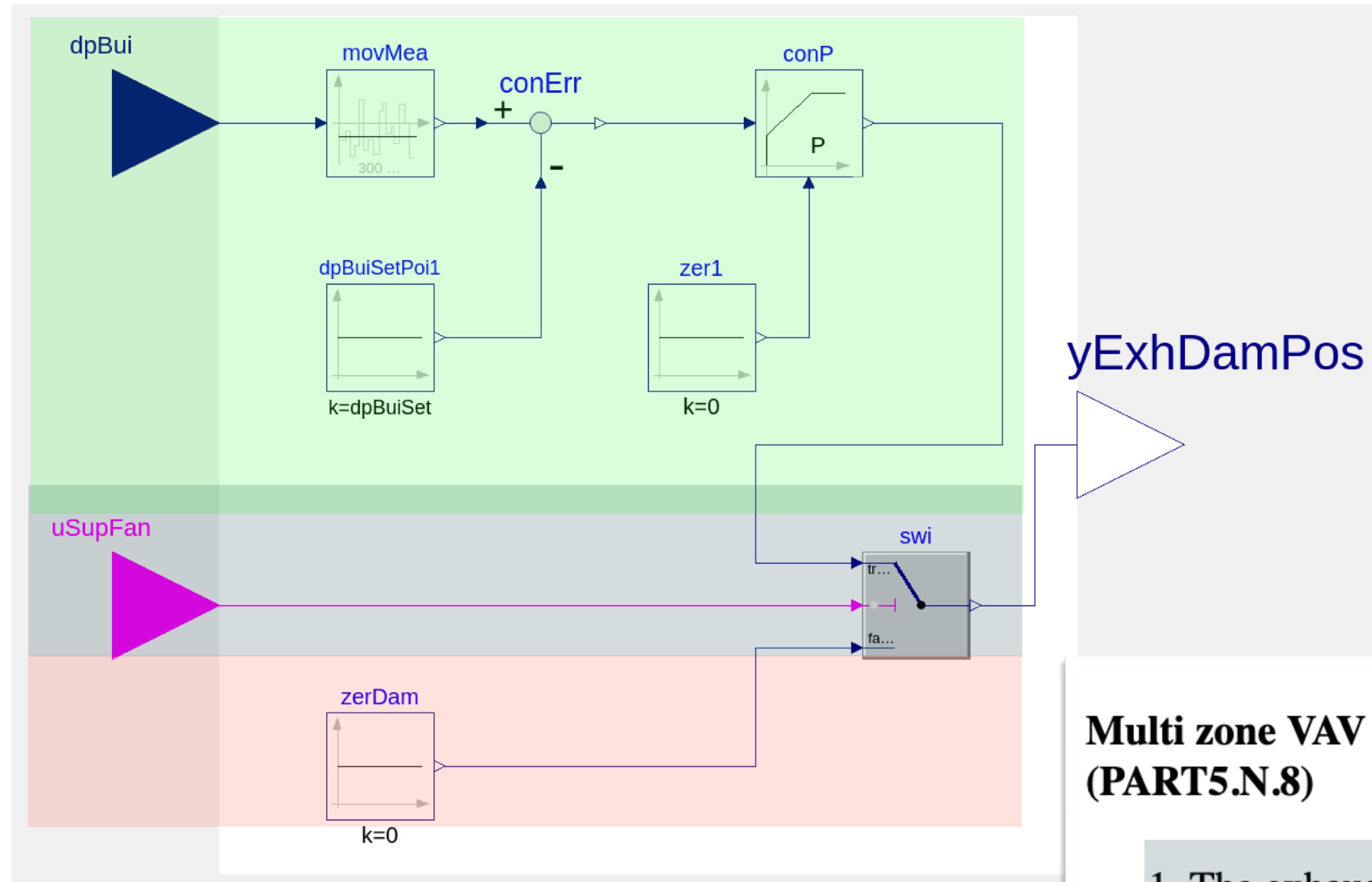
... and allow reuse of technology from the Modelica ecosystem.

Example:

No extends, replaceable, inner/outer, flow, unless all is encapsulated in an Extension Block (<https://obc.lbl.gov/specification/cdl.html#extension-blocks>)



Example Control Sequence in CDL

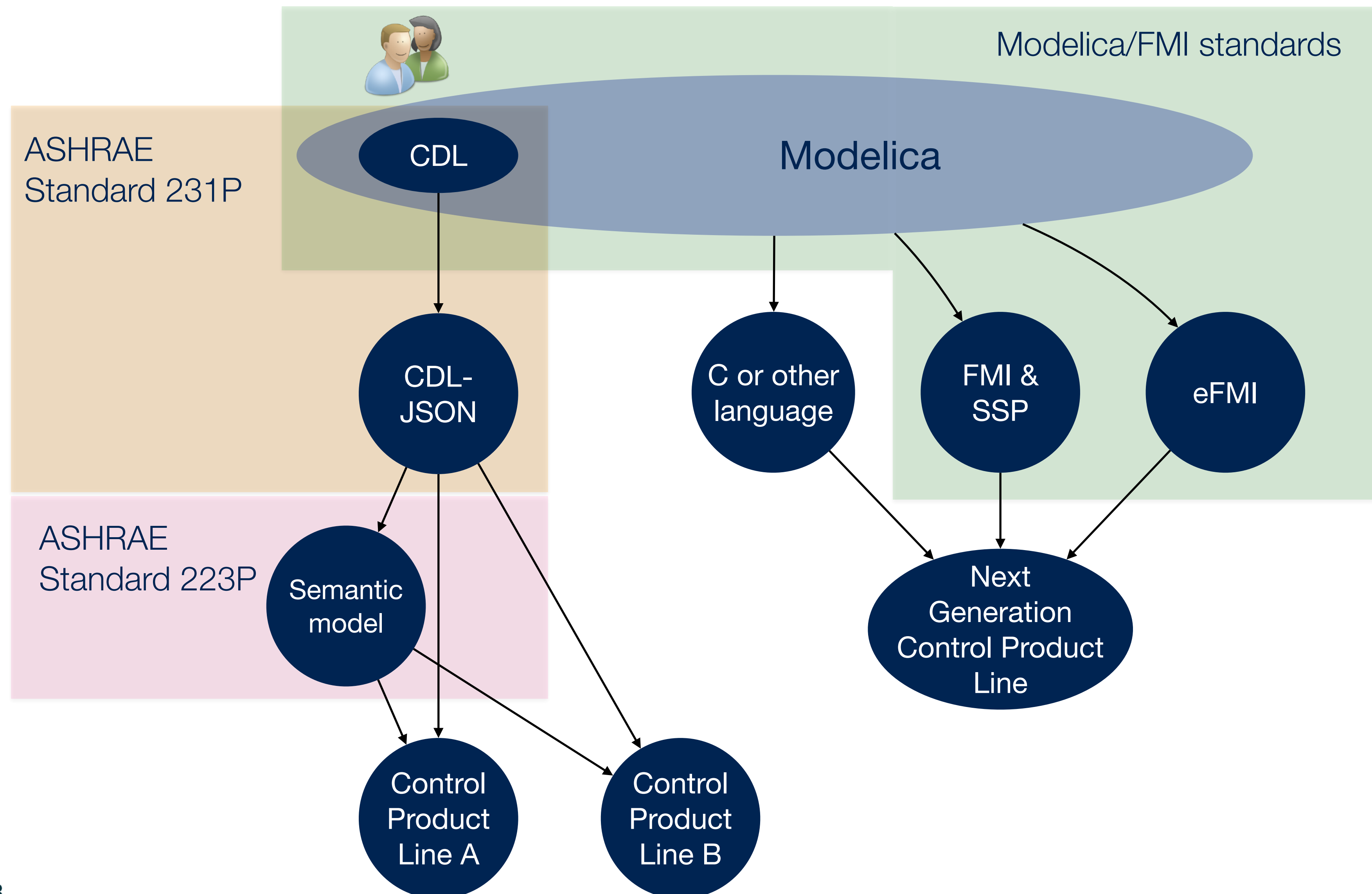


CDL block diagram view

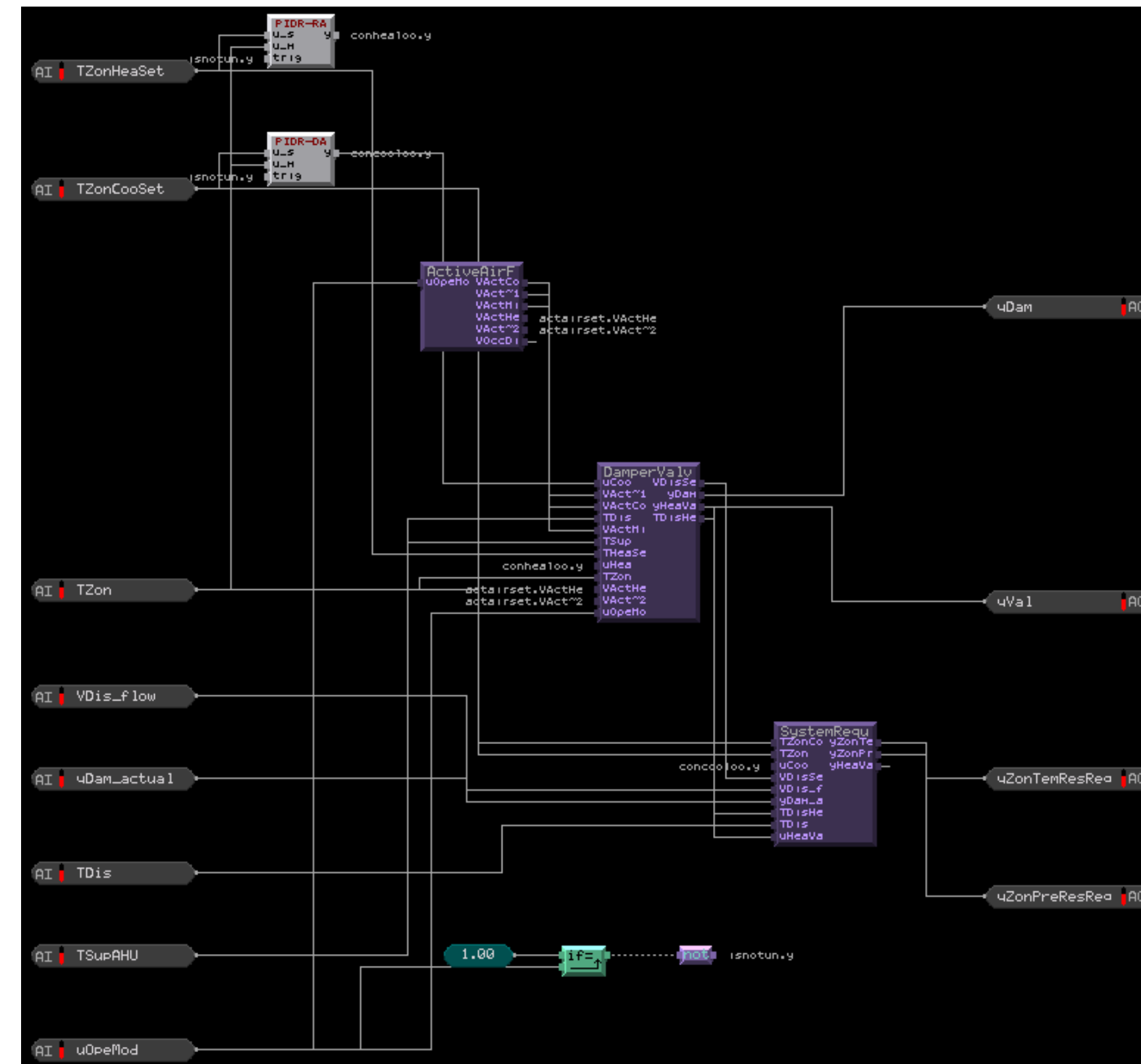
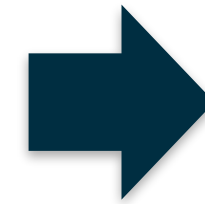
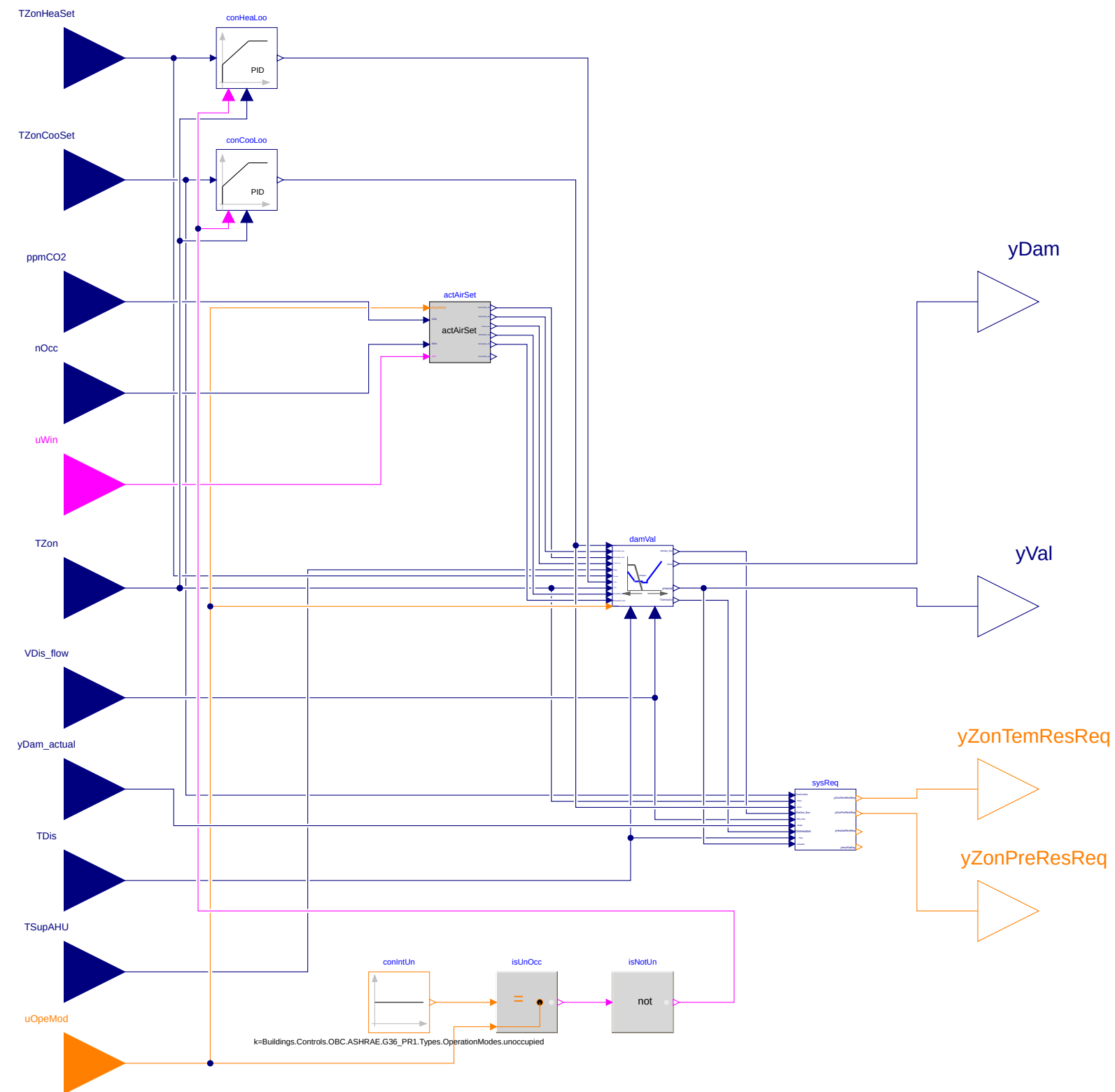
Multi zone VAV AHU: Control of actuated exhaust dampers without fans (PART5.N.8)

1. The exhaust damper is enabled when the associated supply fan is proven on `uFan = true`, and disabled otherwise.
2. When enabled, a P-only control loop modulates the exhaust damper to maintain a building static pressure of `dpBui`, which is by default 12 Pa (0.05 inchWC).
3. When `uFan = false`, the damper is closed.

CDL will allow translation to existing building control product lines and use of FMI Standards



Prototyped machine-to-machine translation from simulation model to a native control product line



Michael Wetter, Paul Ehrlich, Antoine Gautier, Milica Grahovac, Philip Haves, Jianjun Hu, Anand Prakash, Dave Robin and Kun Zhang.
OpenBuildingControl: Digitizing the control delivery from building energy modeling to specification, implementation and formal verification.
Energy, Volume 238, Part A, January 2022.

How does digitalization of control sequences fit into larger ASHRAE, BEM and commissioning ecosystem?

Standard digital control logic representation

A Control Description Language for Building Environmental Control Sequences

Project Committee (PC): 231P

Working Draft No. 02.3

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ASHRAE

GUIDELINE

ASHRAE Guideline 36-2021
(Supersedes ASHRAE Guideline 36-2018)
Includes ASHRAE addenda listed in Appendix C

High-Performance Sequences of Operation for HVAC Systems

See Informative Appendix C for approval dates.

This Guideline is under continuous maintenance by a Standing Guideline Project Committee (SGPC) for which the Standards Committee has established a documented program for regular publication of addenda or revisions, including procedures for timely, documented, consensus action on requests for change to any part of the Guideline. Instructions for how to submit a change can be found on the ASHRAE website (<https://www.ashrae.org/continuous-maintenance>).

The latest edition of an ASHRAE Guideline may be purchased from the ASHRAE website (www.ashrae.org) or from ASHRAE Customer Service, 180 Technology Parkway NW, Peachtree Corners, GA 30092. E-mail: orders@ashrae.org. Fax: 404-529-2125. Telephone: 404-529-8800 (toll-free), or toll-free: 1-800-527-4723 (for orders in US and Canada). For reprint permission, go to www.ashrae.org/pam/is/cons.

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includes download access to the standard in Microsoft® Word® format.

CDL sequence implementations

- CDL
 - Continuous
 - Conversions
 - Discrete
 - DayType
 - FirstOrderHold
 - Sampler
 - TriggeredMax
 - TriggeredSampler
 - UnitDelay

- ASHRAE
 - G36
 - AHUs
 - Generic
 - TerminalUnits
 - ThermalZones
 - VentilationZones
 - ZoneGroups
 - Types
 - PrimarySystem
 - ChillerPlant
 - Controller
 - Economizers
 - Generic
 - HeadPressure
 - MinimumFlowBypass
 - Pumps
 - SetPoints
 - Staging
 - Towers

Sequence configuration

ctrl-flow

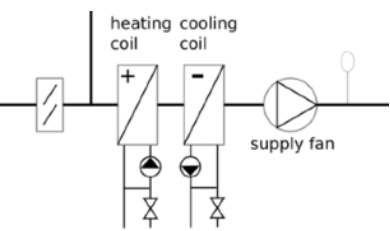
Welcome to ctrl-flow, the High Performance Controls Design Tool

Systems Configure Results

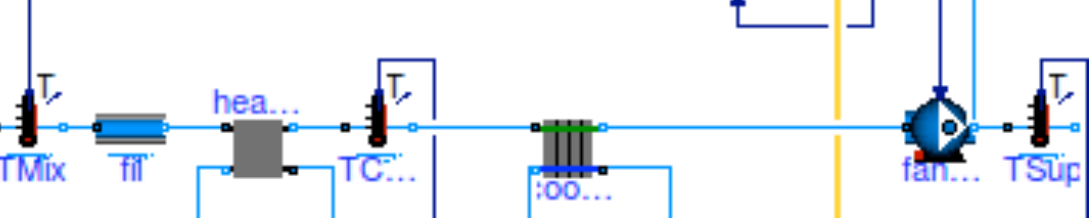
Writing a detailed and accurate control sequence is hard to do! This tool makes it easy to design high performance control sequences following ASHRAE Guideline 36 and best practices. After inputting project details, the tool will produce a detailed sequence of operations document.

CONTINUE

ctrl-flow



Annual energy simulation



Implementation

Manual Override

CH STPT FLOW 53.24

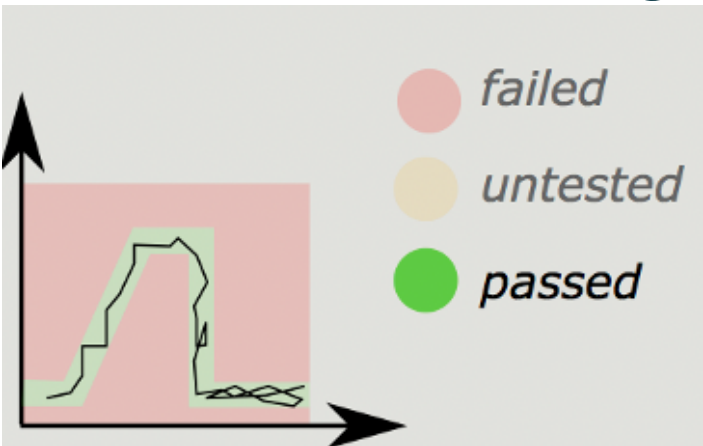
SP 53.24

in d

AV 0

EV Off

Formal testing and/or commissioning



Legend

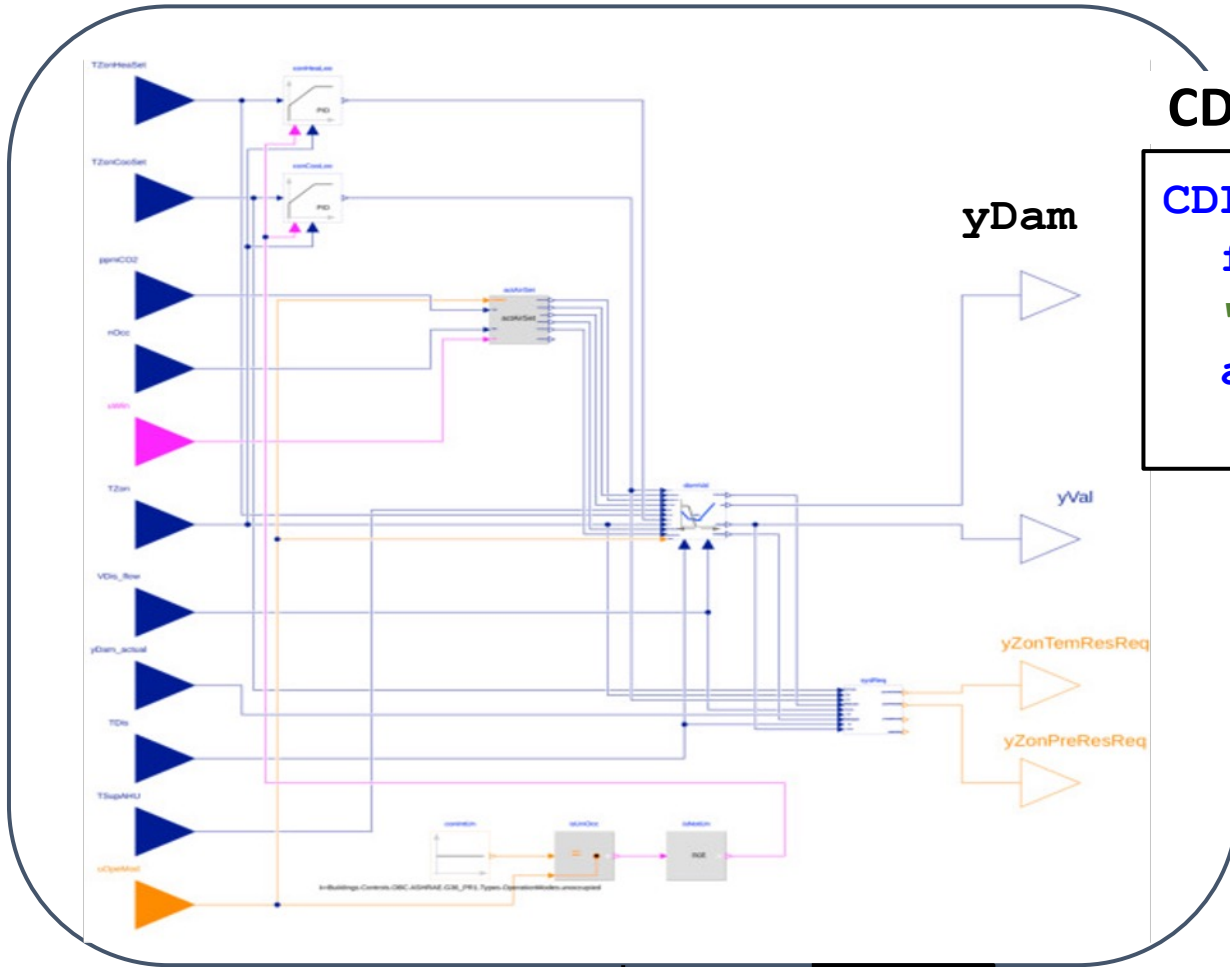
- Implemented
- Prototyped
- Designed/specified

2024-25?: Code generation for cloud offerings or embedded controller

Integrating standards for
robust control digitalization

Combining control logic and semantic models

Generic VAV terminal box control logic (CDL)



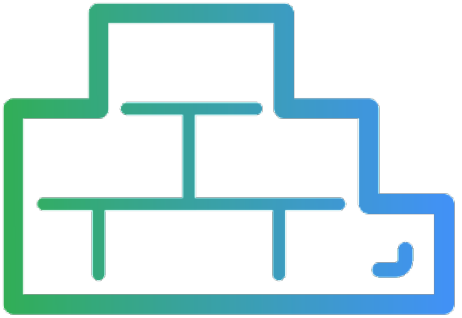
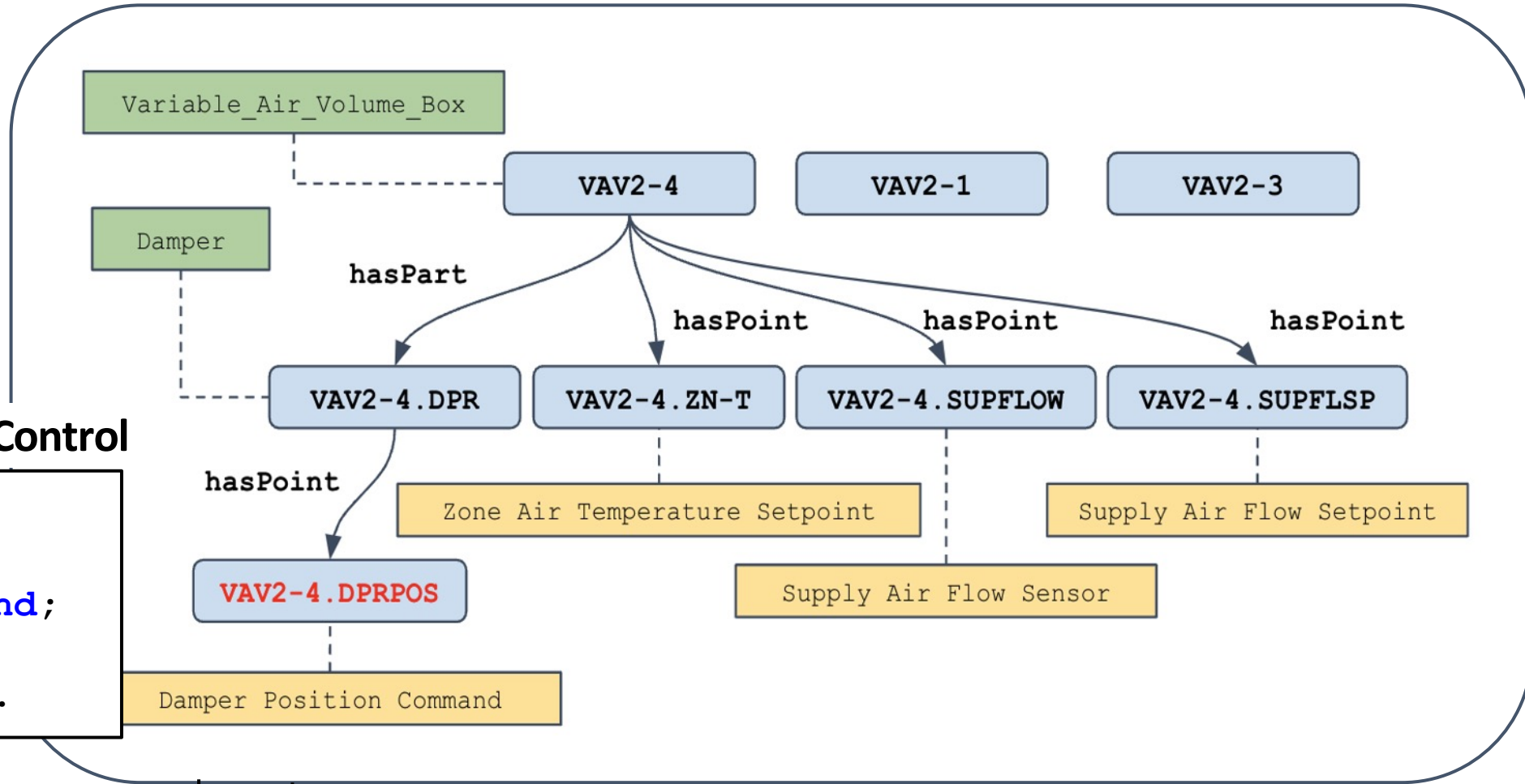
CDL for yDam VAV Damper Position Control

```
CDL.Interfaces.RealOutput yDam (  
  final min=0, final max=1, final unit="1"  
  "Signal for VAV damper"  
  annotation (__semantic(standard="brick"  
    "a brick:Damper_Command .")) ;  
)
```

brick for VAV2-4.DPRPOS Damper Position Control

```
:VAV2-4 a brick:VAV ;  
brick:hasPart :VAV2-4.DPR  
:VAV2-4.DPRPOS a brick:Damper_Command ;  
brick:isPointOf :VAV2-4.DPR  
bacnet:object-name "DMP_CM_2-4" .
```

Building-specific semantic model (Brick)



Brick



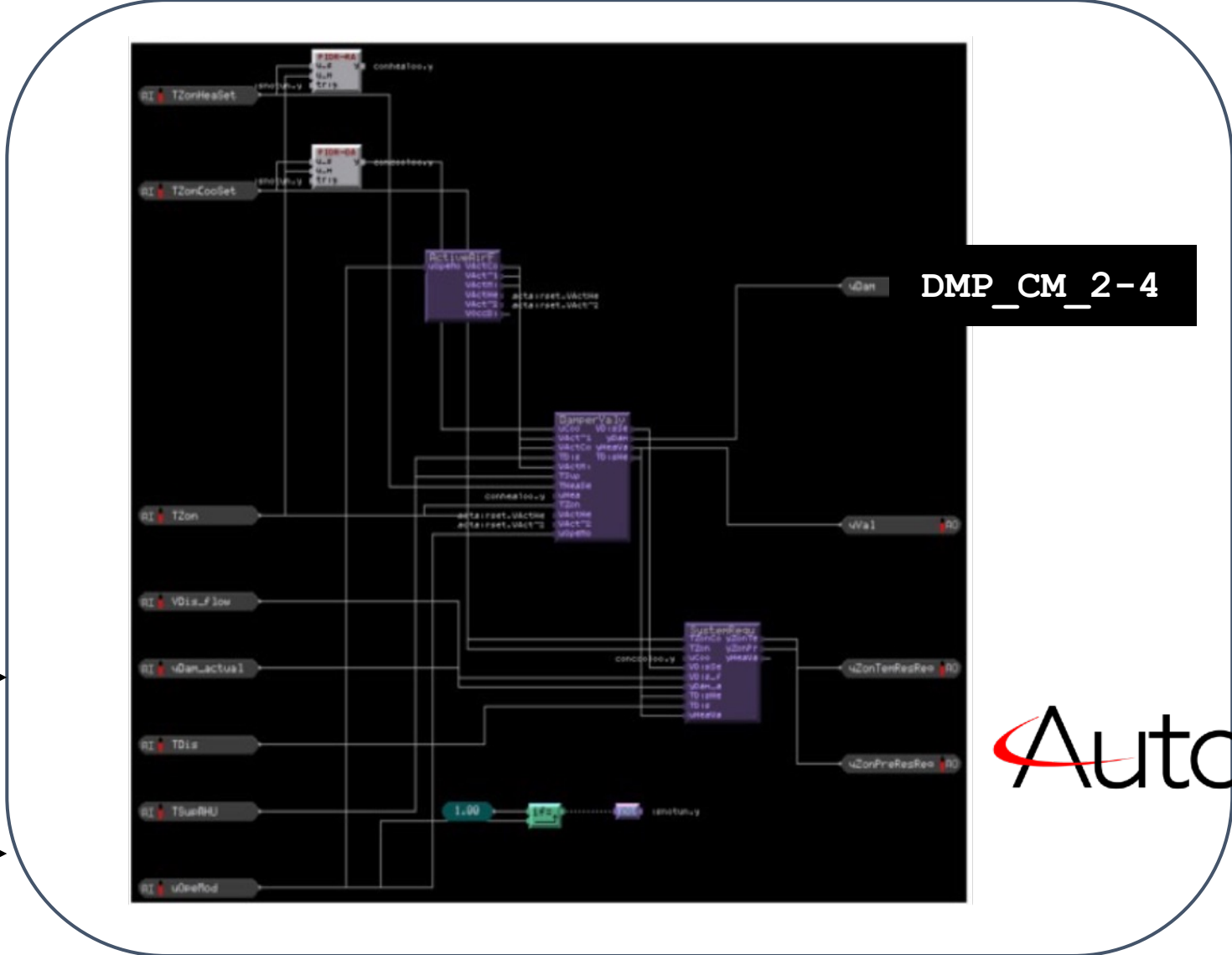
SPARQL query for finding VAV boxes in Brick model

```
SELECT ?vav WHERE {  
  ?vav a brick:VAV ;  
}  
Result: {"VAV2-4", "VAV2-1", "VAV2-3"}
```

SPARQL query for finding BACnet point name of VAV2-4 Damper Position control

```
SELECT ?dprpos ?point WHERE {  
  ?dprpos a brick:Damper_Command ;  
  brick:isPointOf+ :VAV2-4 ;  
  bacnet:object-name ?point .  
}  
Result: {"VAV2-4.DPRPOS", "DMP_CM_2-4"}
```

Building-specific VAV box control logic (ALC)



Questions

Michael Wetter
mwetter@lbl.gov

References

ctrl-flow.lbl.gov

<https://obc.lbl.gov/specification/cdl.html>

Michael Wetter, Paul Ehrlich, Antoine Gautier, Milica Grahovac, Philip Haves, Jianjun Hu, Anand Prakash, Dave Robin and Kun Zhang.

OpenBuildingControl: Digitizing the control delivery from building energy modeling to specification, implementation and formal verification.

Energy, Volume 238, Part A, January 2022.

Michael Wetter, Milica Grahovac and Jianjun Hu.

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1st American Modelica Conference, Cambridge, MA, USA, August 2018.

Amir Roth, Michael Wetter, Kyle Benne, David Blum, Yan Chen, Gabriel Fierro, Marco Pritoni, Avijit Saha and Draguna Vrabie.

Towards Digital and Performance-Based Supervisory HVAC Control Delivery.

ACEEE Summer Study on Energy Efficiency in Buildings, p. 3-528--3-543, Pacific Grove, CA, August, 2022.