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How to faithfully model systems composed of millions of parts?

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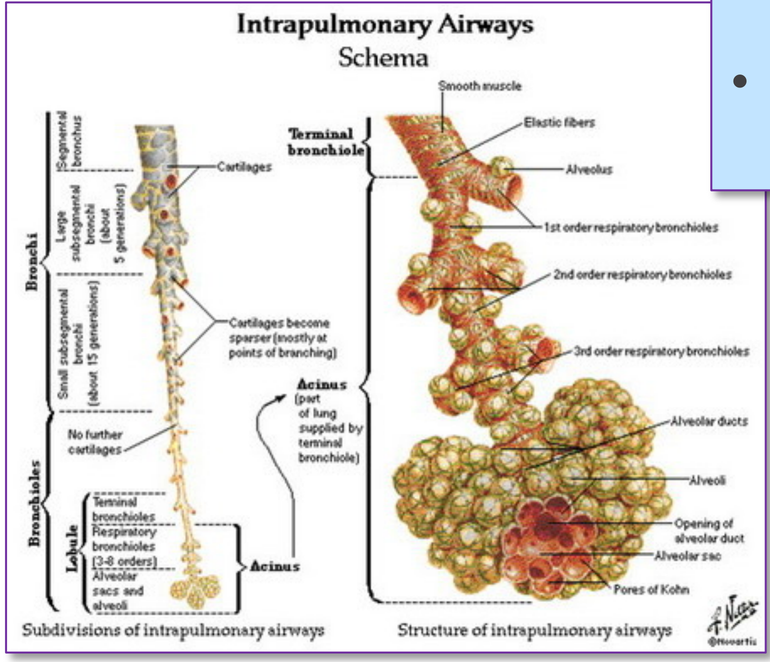
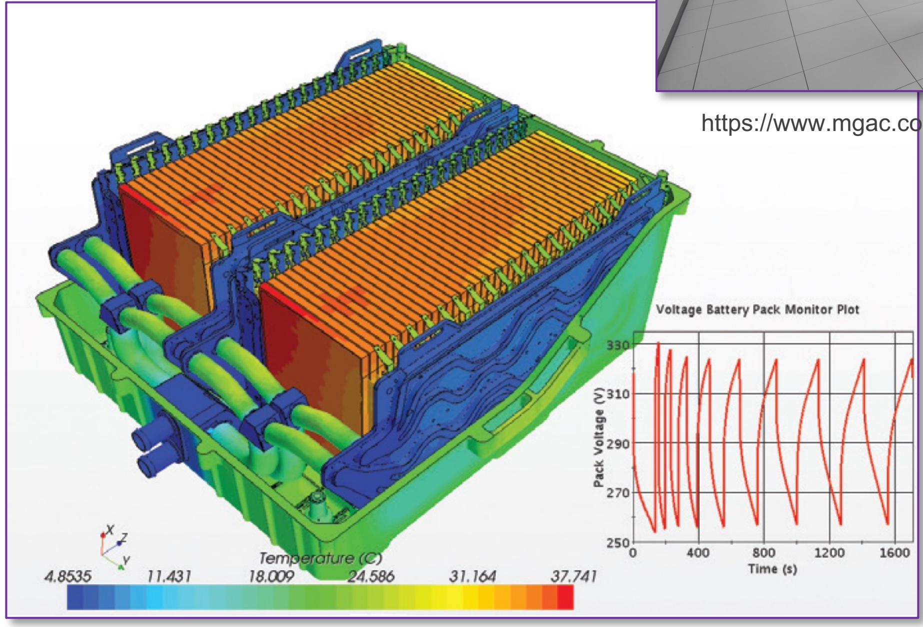
The Challenge – Modeling Ultra Complex Systems

- Critical systems in our world
- Thousands or millions of elements
- Impossible to model directly by hand



https://web.as.uky.edu/Biology/faculty/cooper/KMA/lungs%20pdf.pdf

https://www.mgac.com/blog/6-models-of-the-modern-data-center/



Siemens-SW-Designing-tomorrows-Li-ion-battery-White-Paper_tcm27-101035.pdf

Suppose we need to model the behavior of a single user session of an application in a data center.

Example 1 – Data Center

Example: User Session in a Data Center

Consider the problem of modeling a single user session of an enterprise software application hosted somewhere in a data center.

The data center consists of many rows of 24 inch / 42 U equipment racks.

Example: User Session in a Data Center

A standard equipment rack is 24 inches (~600mm) wide and has 42 evenly spaced mounting holes on each side.

IT equipment comes in multiples of “U” vertical width. Here is a typical “6U” blade server chassis with a number of slots.

Each slot in the blade chassis contains a server blade with 1 to 4 server-class microprocessors, each with as many as 40 cores.

Example: User Session in a Data Center

A server might contain multiple hardware partitions, each with its own hypervisor.

vmware

Linux

A single hypervisor might be managing dozens or hundreds of virtual machines, each with an operating system.

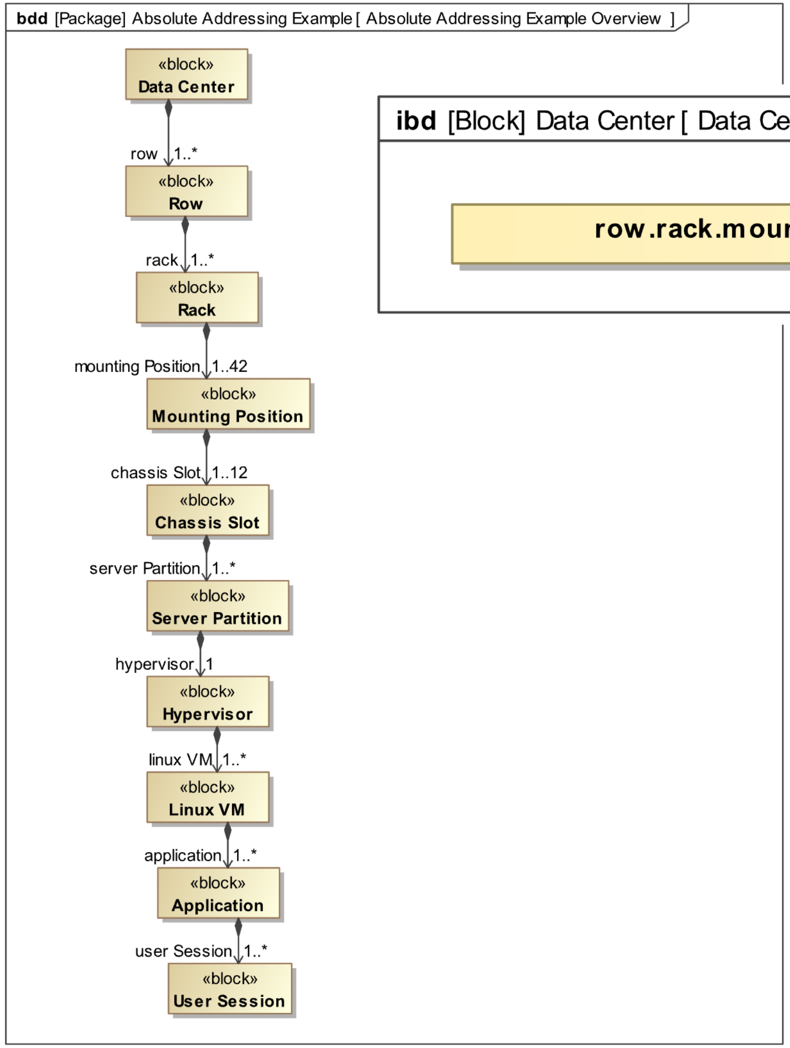
Application

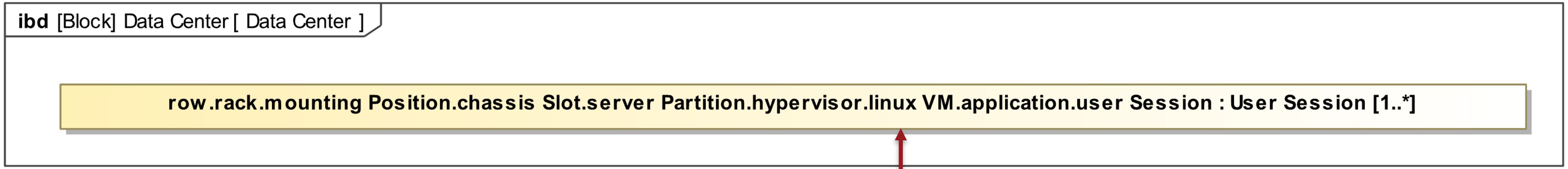
Each operating system image might be managing multiple applications.

User Session

Each Application might be managing dozens of user sessions, each in its own thread.

Example: SysML Approach





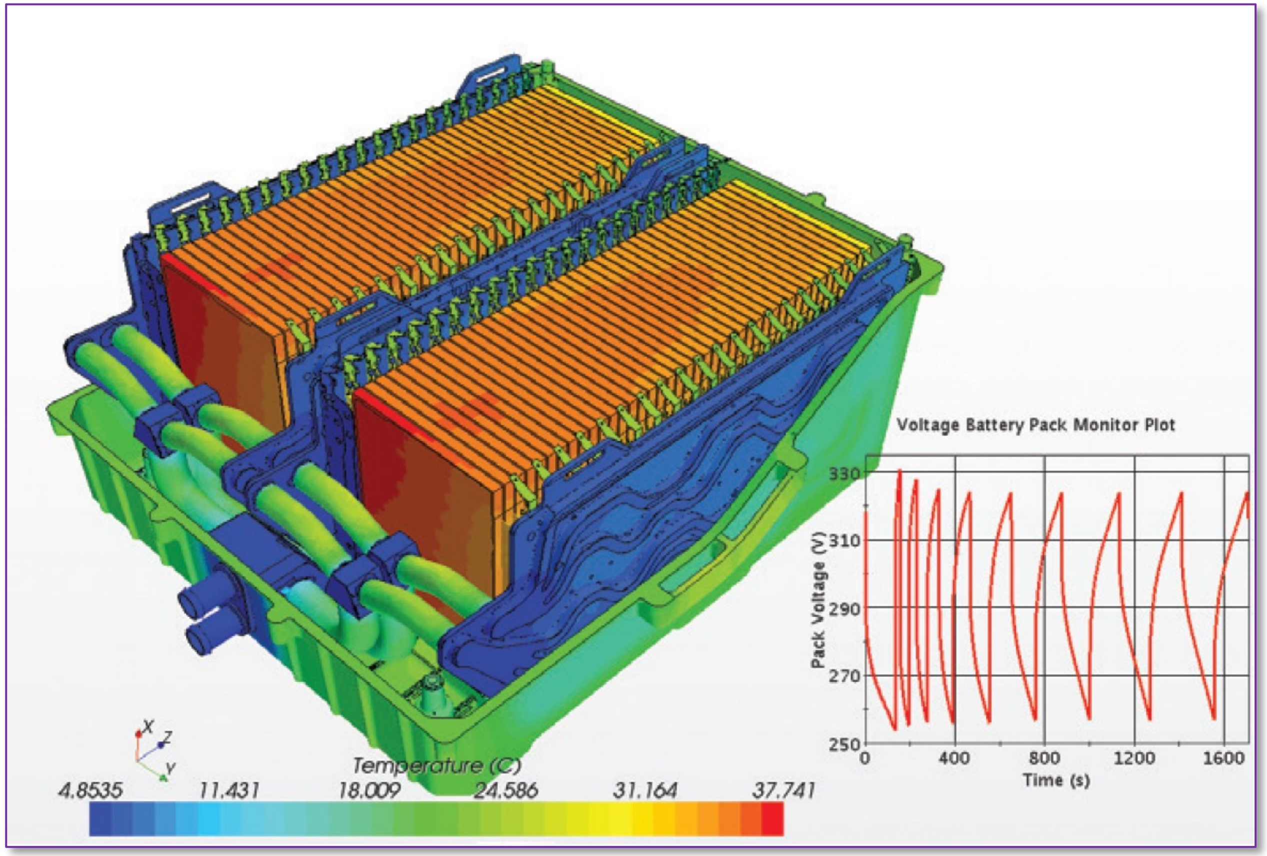
Very cumbersome absolute addressing "dot" notation.

(SysML and UML do not provide for direct indexing of a single element within a multiplicity.)

What if we need to directly model an automotive battery pack?

Example 2 – Battery Pack

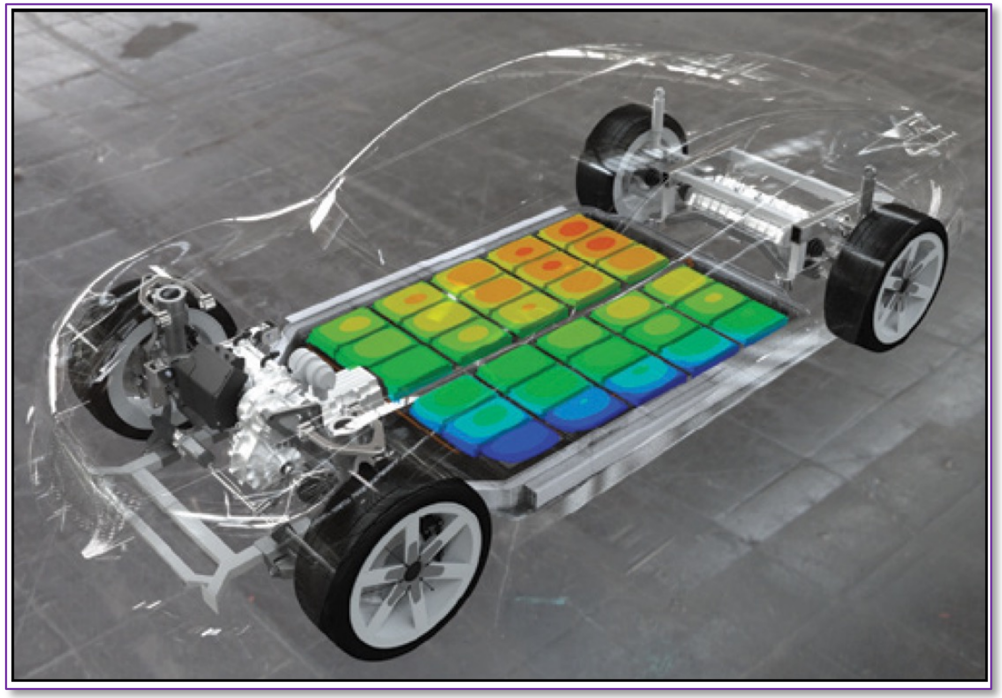
Battery Pack



Siemens-SW-Designing-tomorrows-Li-ion-battery-White-Paper_tcm27-101035.pdf

- Thousands (not millions) of elements.
- However, the "interfaces" to the elements depend heavily on where the specific element is in the physical structure of the pack.

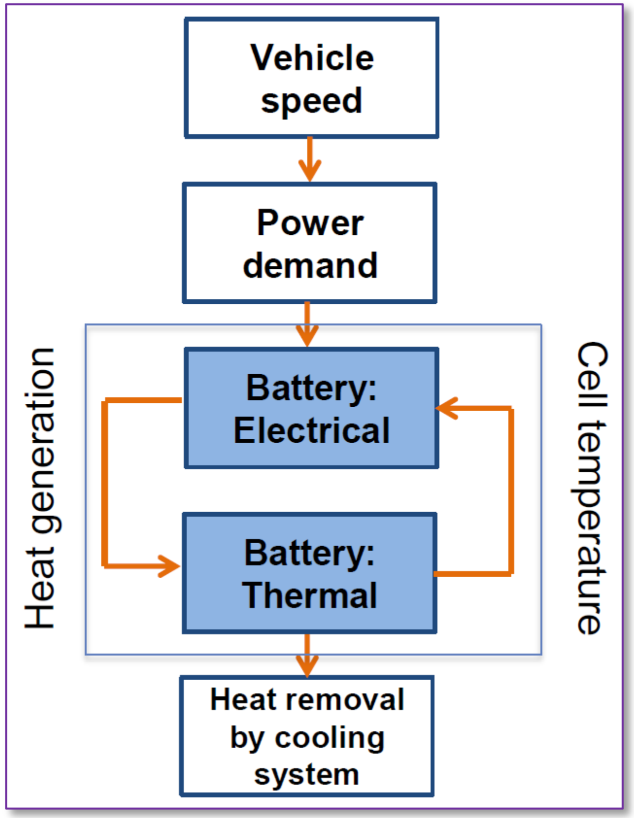
Battery Simulation



SAE Battery & Electrification Technology, May 2022

- Although cells may be identical, hot and cold areas in a battery will depend on the location of the cells

- Electrical and thermal performance are tightly coupled.

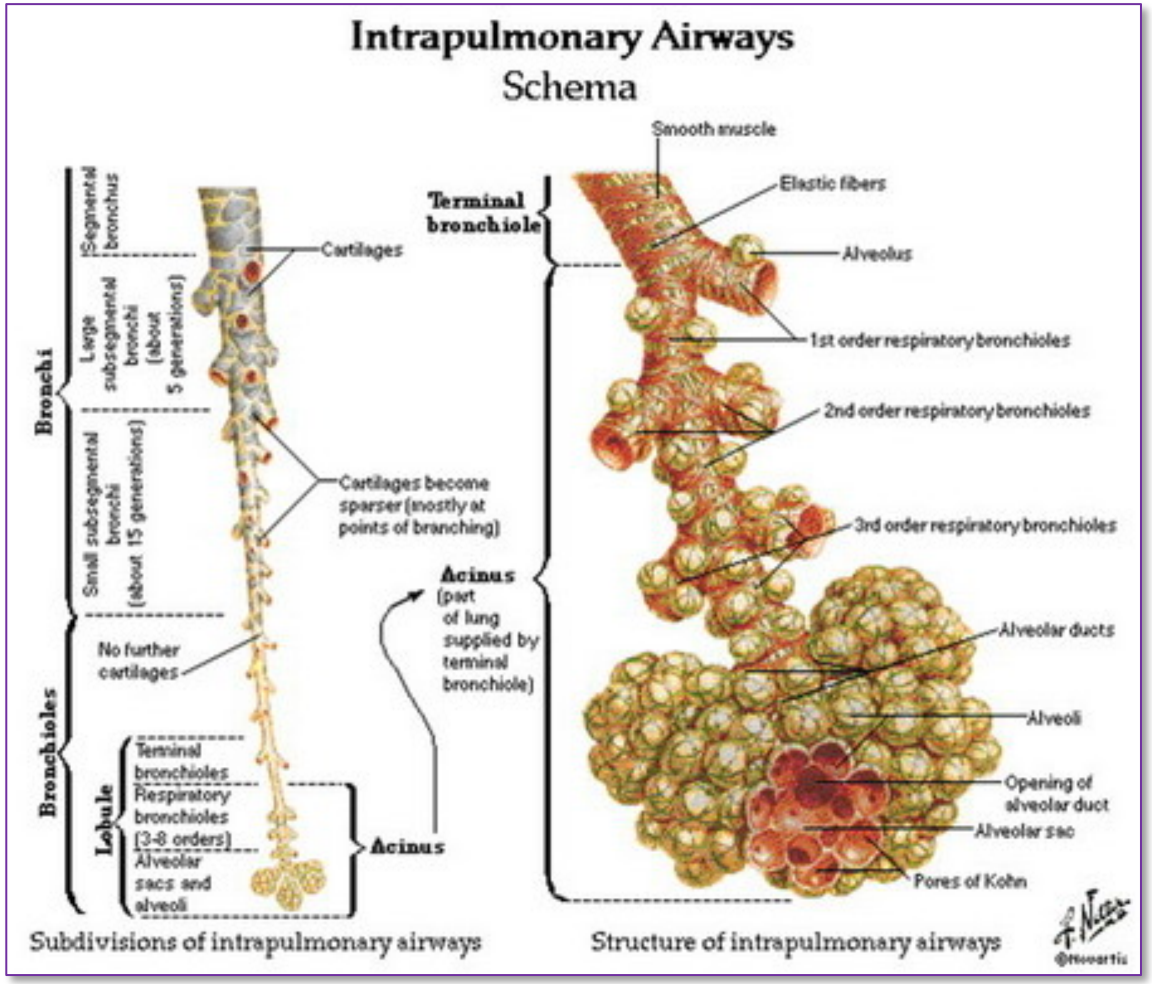


Development and Application of Liquid-cooled Lithium-ion Battery Pack Thermal Model, Model based approach by using GT-SUITE - North American GT Conference 2017, Fiat Chrysler Automobiles

Modeling the gas exchanges in a human lung would be complicated as well.

Example 3 – Human Lung

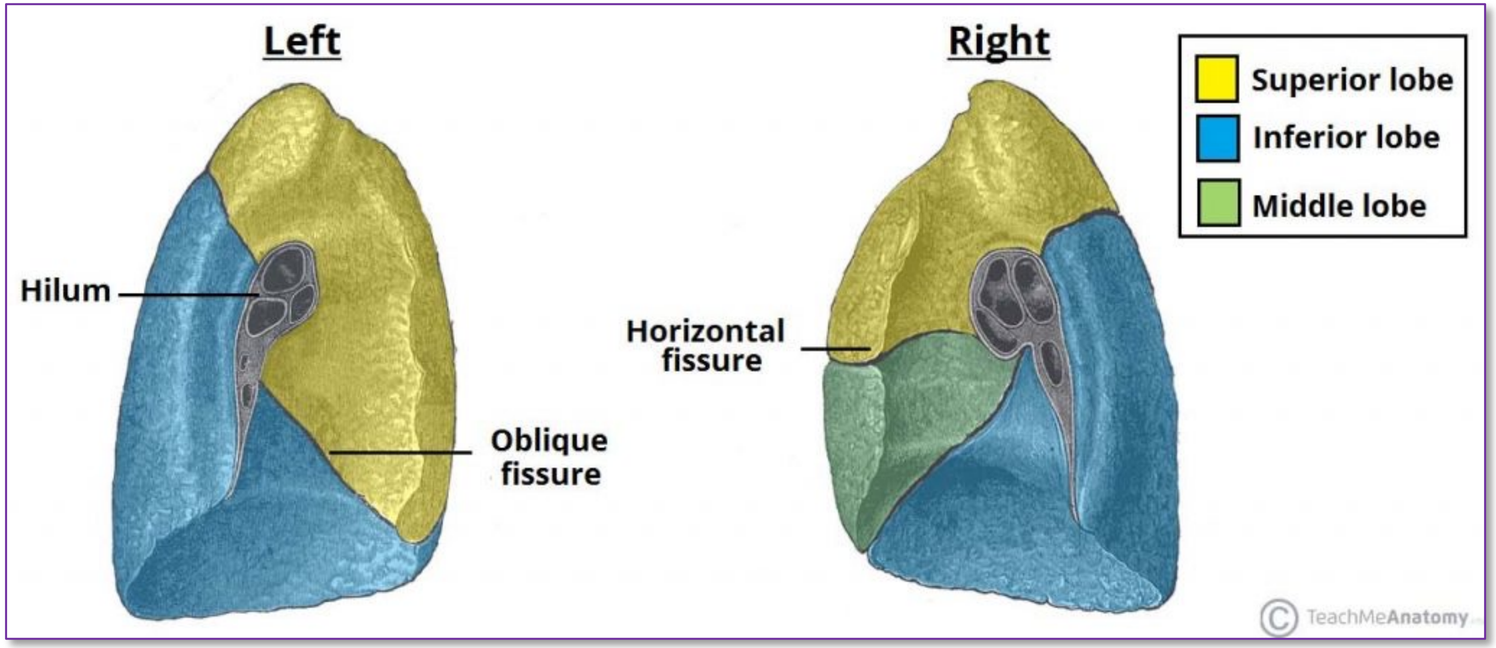
Human Lung



https://web.as.uky.edu/Biology/faculty/cooper/KMA/lungs%20pdf.pdf

- About 28 orders of division in the tracheo-bronchial tree.
- Estimated 200-400 million alveoli with 40-80 square meters of surface area.

Human Lung Structural Patterns



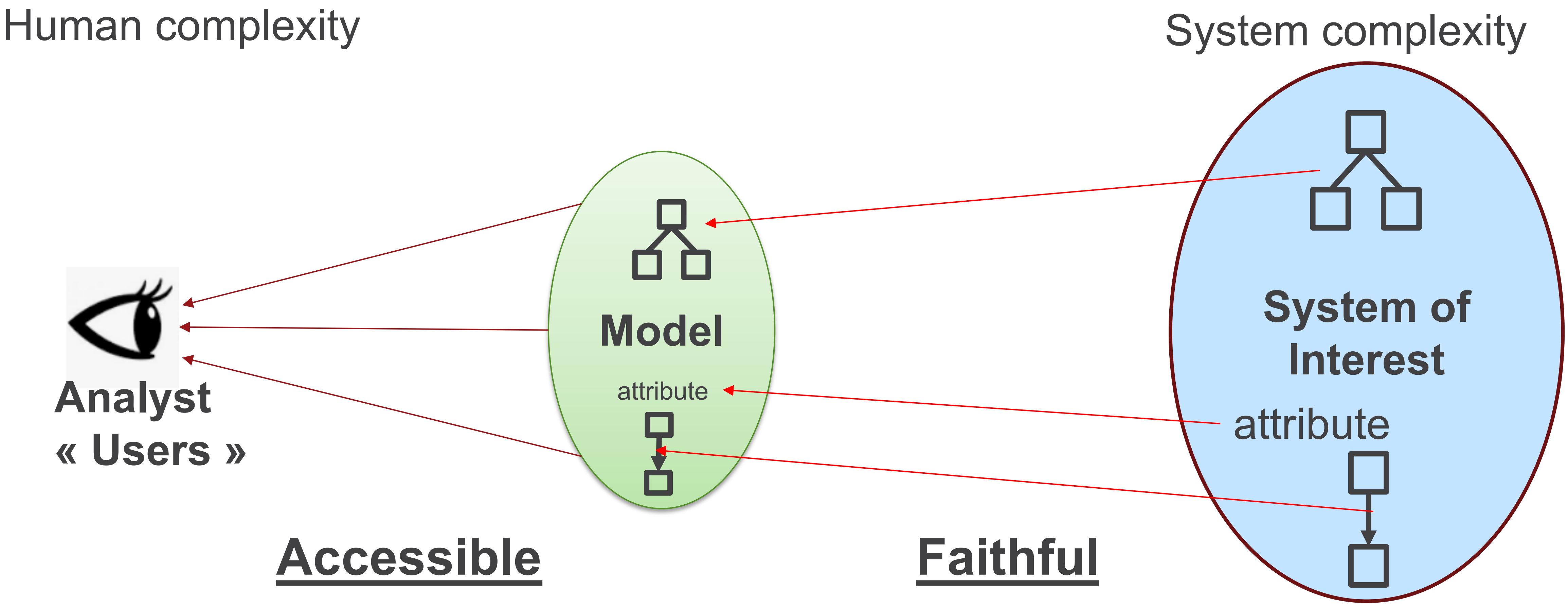
https://teachmeanatomy.info/thorax/organs/lungs/

- Although the lungs appear to be uniformly structured, actually they aren't
- Right and left lungs are different.
- The lobes within each lung are different.
- A straight multiplicity model will not be sufficient.

First and foremost, the model has to help the users understand the system.

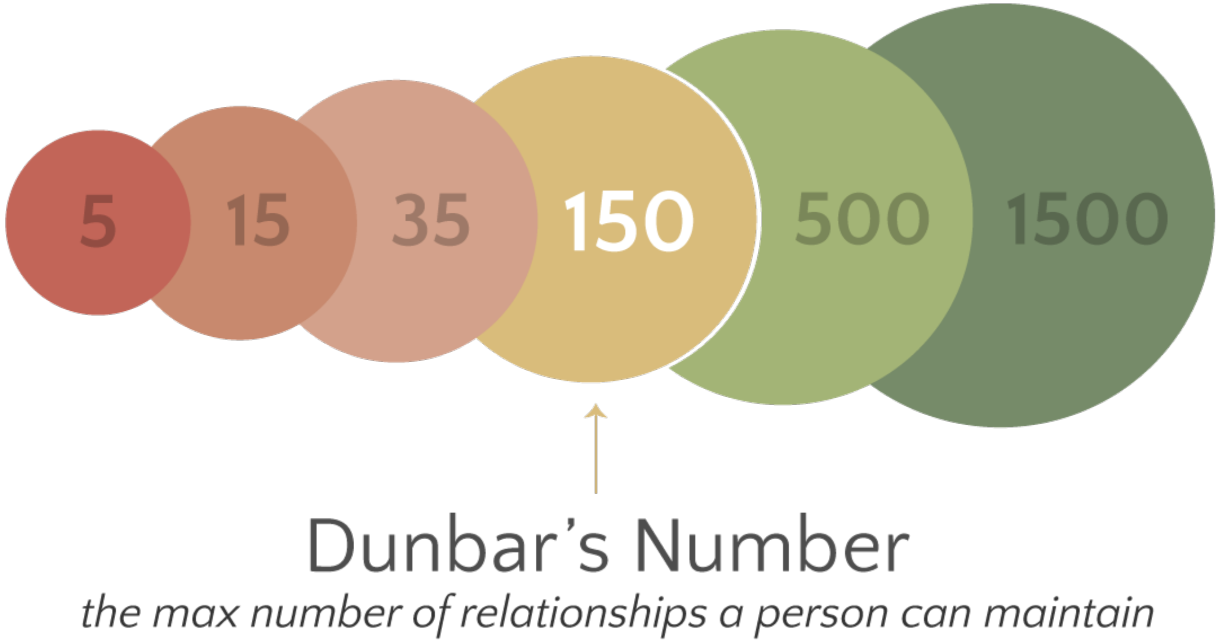
Challenges of Modeling

Expectation about Models



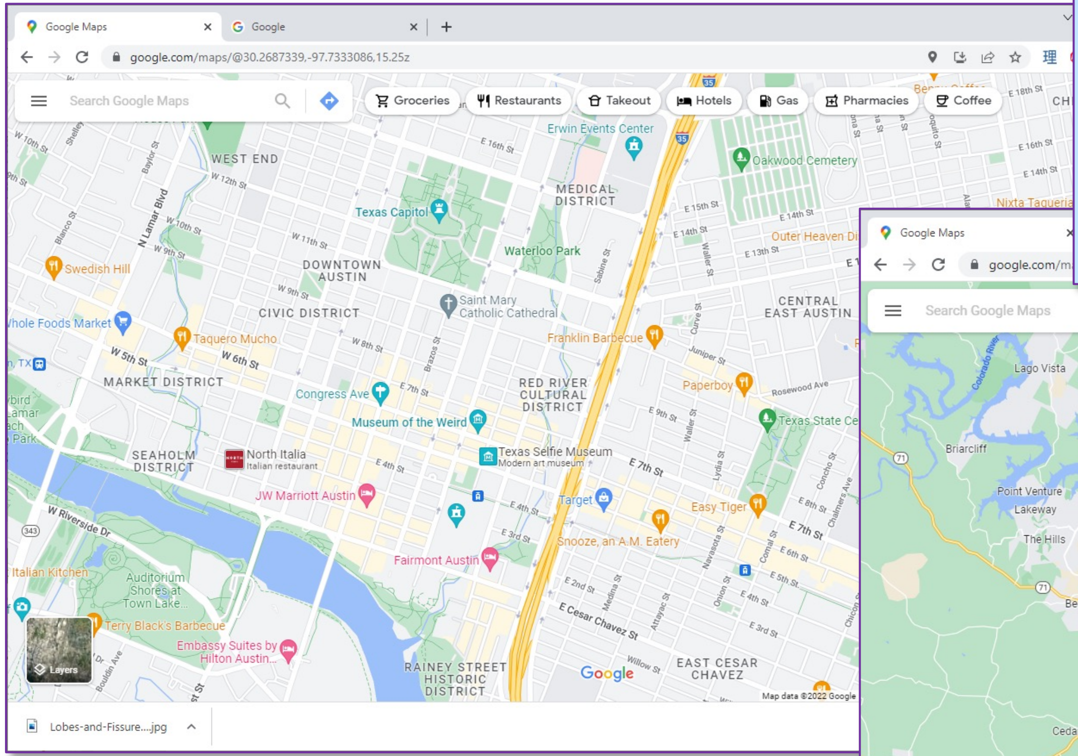
Dunbar’s Number

- Widely discussed in studies of social media
- Exact number is hard to nail down, but general effect is well understood.
- Many examples of military and corporate structures organized around 200.
- **Assertion:** Although usually thought of as related to human relationships, *there is similar limit of the number of elements in a model that a human can think about before becoming overwhelmed*.

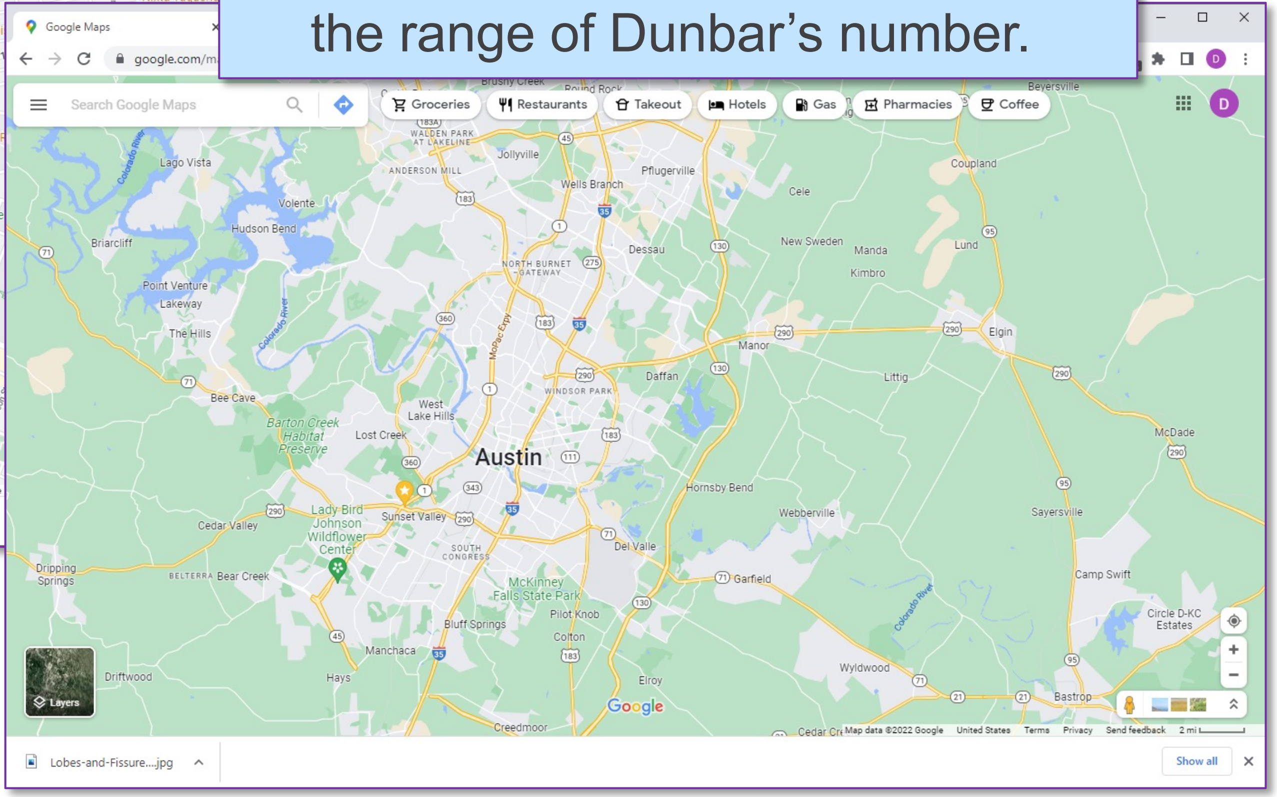


https://en.wikipedia.org/wiki/Dunbar%27s_number

Google Maps



- Google Maps presents roughly the same amount of information at every zoom level.
- Counting geometric detail the number of information points is in the range of Dunbar's number.



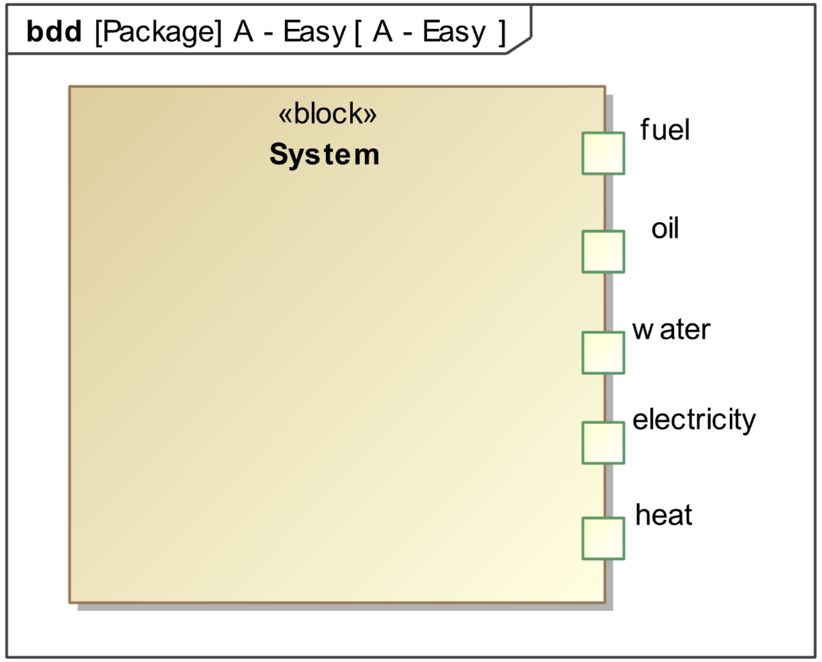
Miller's Law

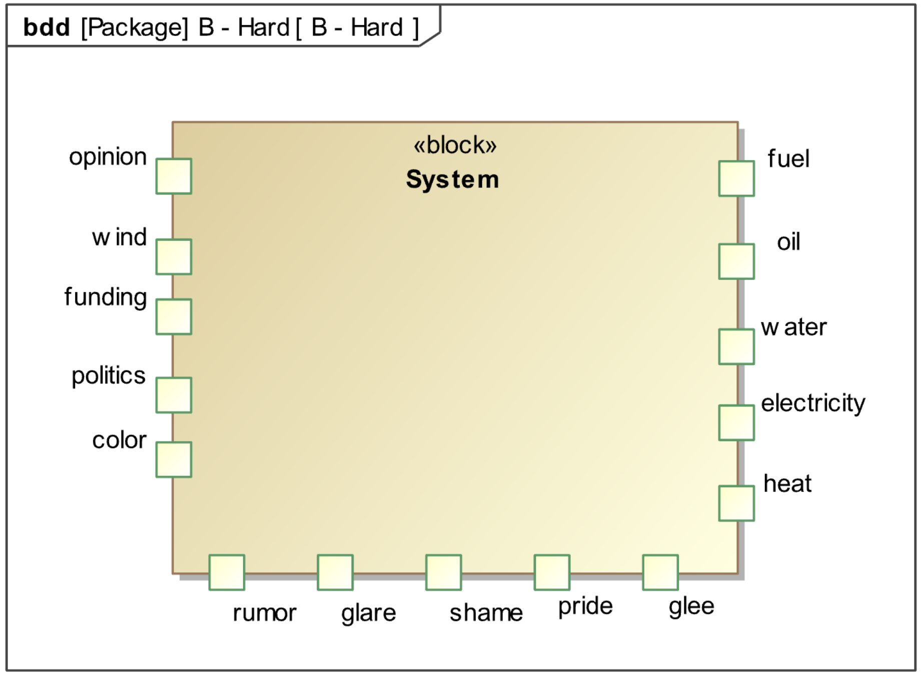
- 1956 article in Psychology Review by George Miller of the Harvard University Department of Psychology
- Limits of short-term memory
- **Assertion:** Although usually thought of as related to human short term memory, *there is similar limit of the number of similar elements in a model diagram before users start having difficulty comprehending the diagram*

"Seven plus or minus two"

https://en.wikipedia.org/wiki/The_Magical_Number_Seven,_Plus_or_Minus_Two

Ports Example





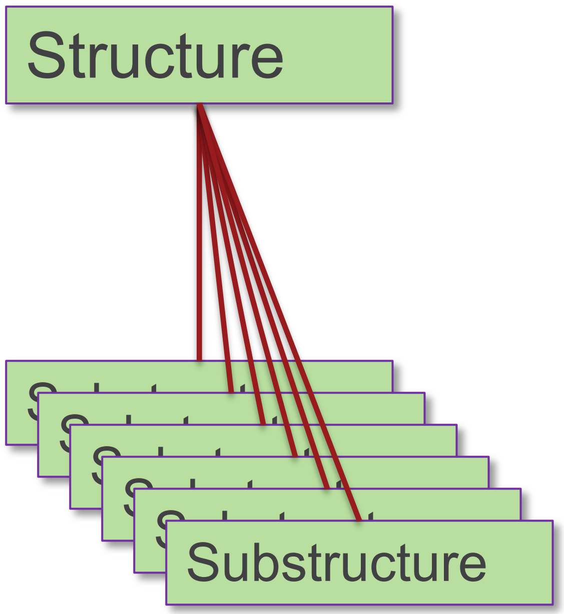
- The system with 5 ports is easy to think about

- The system with 15 ports requires a lot more concentration to understand.

Clearly, a modular approach will be needed

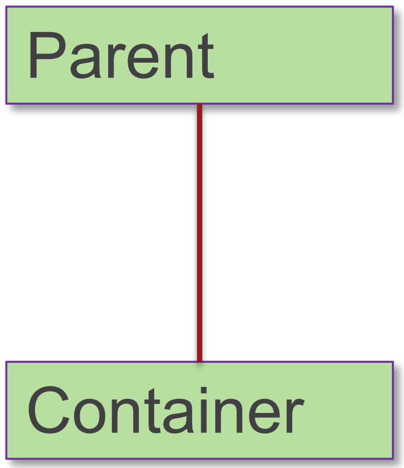
Complexity Reduction Strategy

Approach: Simplifying Hierarchical Relationships



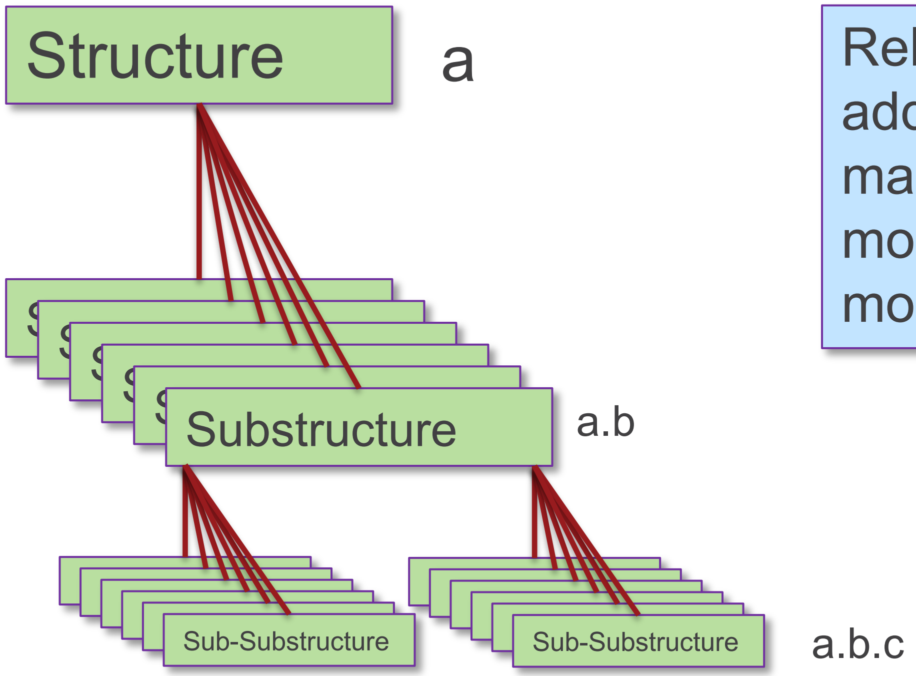
The real system is like this.

The simpler modeling helps us with the Dunbar Number and Miller's Law problem

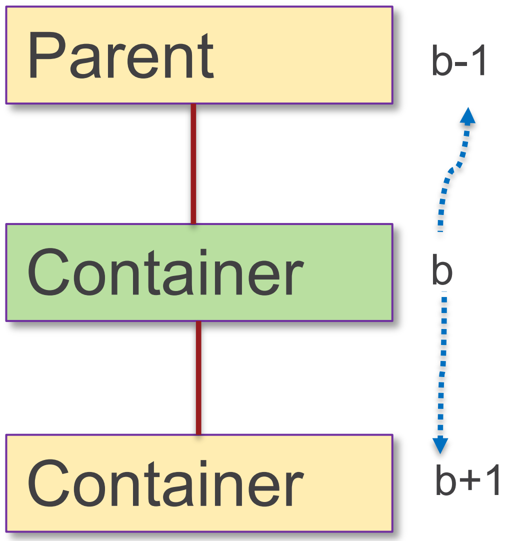


We model this.

Approach: Absolute versus Relative References



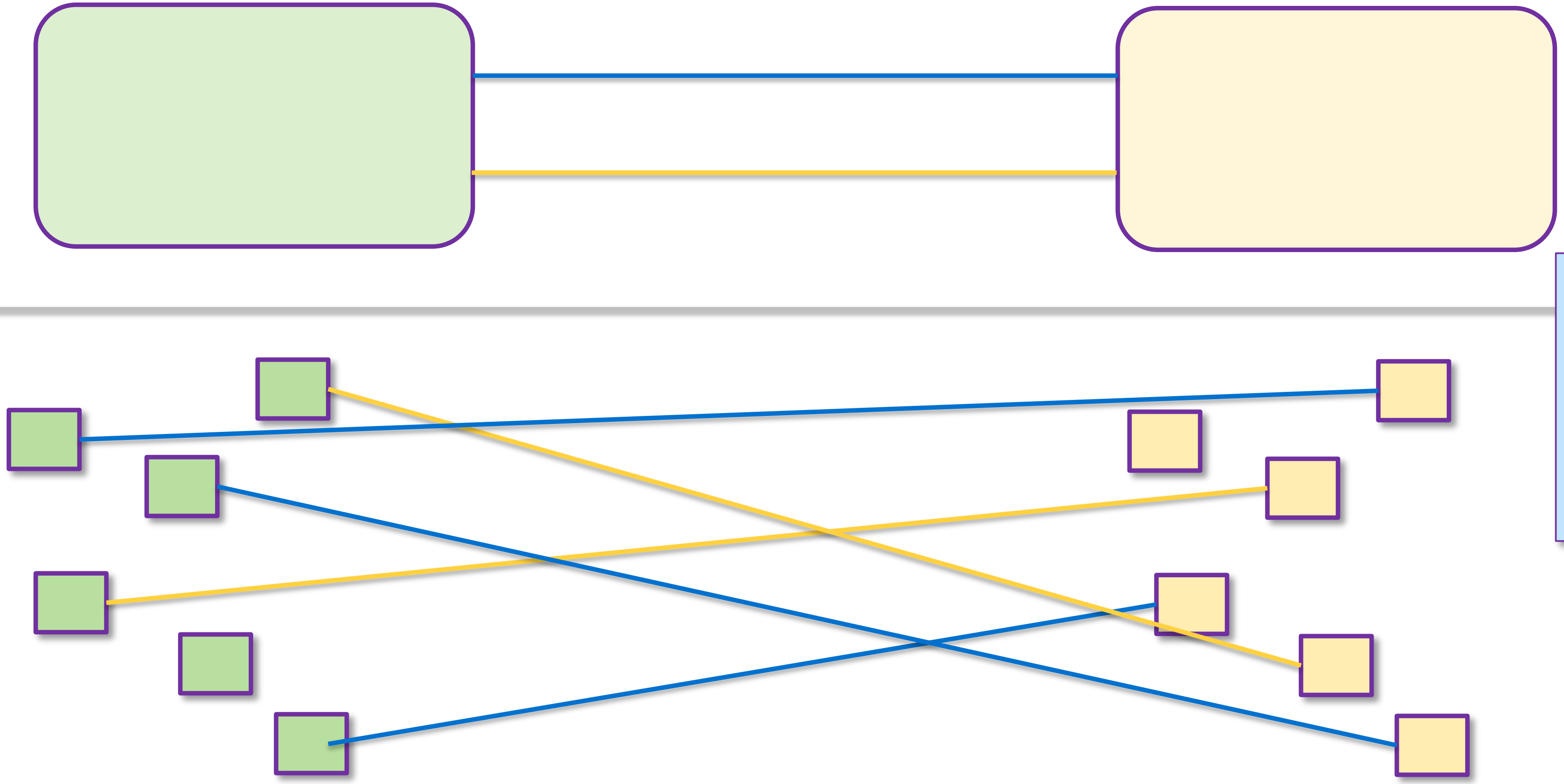
Relative addressing makes our model more modular.



Absolute strategy

Relative strategy

Approach: Reducing Interface Complexity



How to group and bundle interfaces to enable "Zoom Out"

Although the cells seem similar, their thermal interfaces depend on their location in the structure.

Modeling the Battery Pack

Parametric Models an Example

Case of a battery structure:

We present an example.
Here parameters are lists of integers
m = [1..6] several modules [m]
sl = [1..3] number of slavemodules[sl] per [m]
cp = [1..32] number of cell packs[cp per [sl]
c = [1..30] number of cells[c] per [cp]

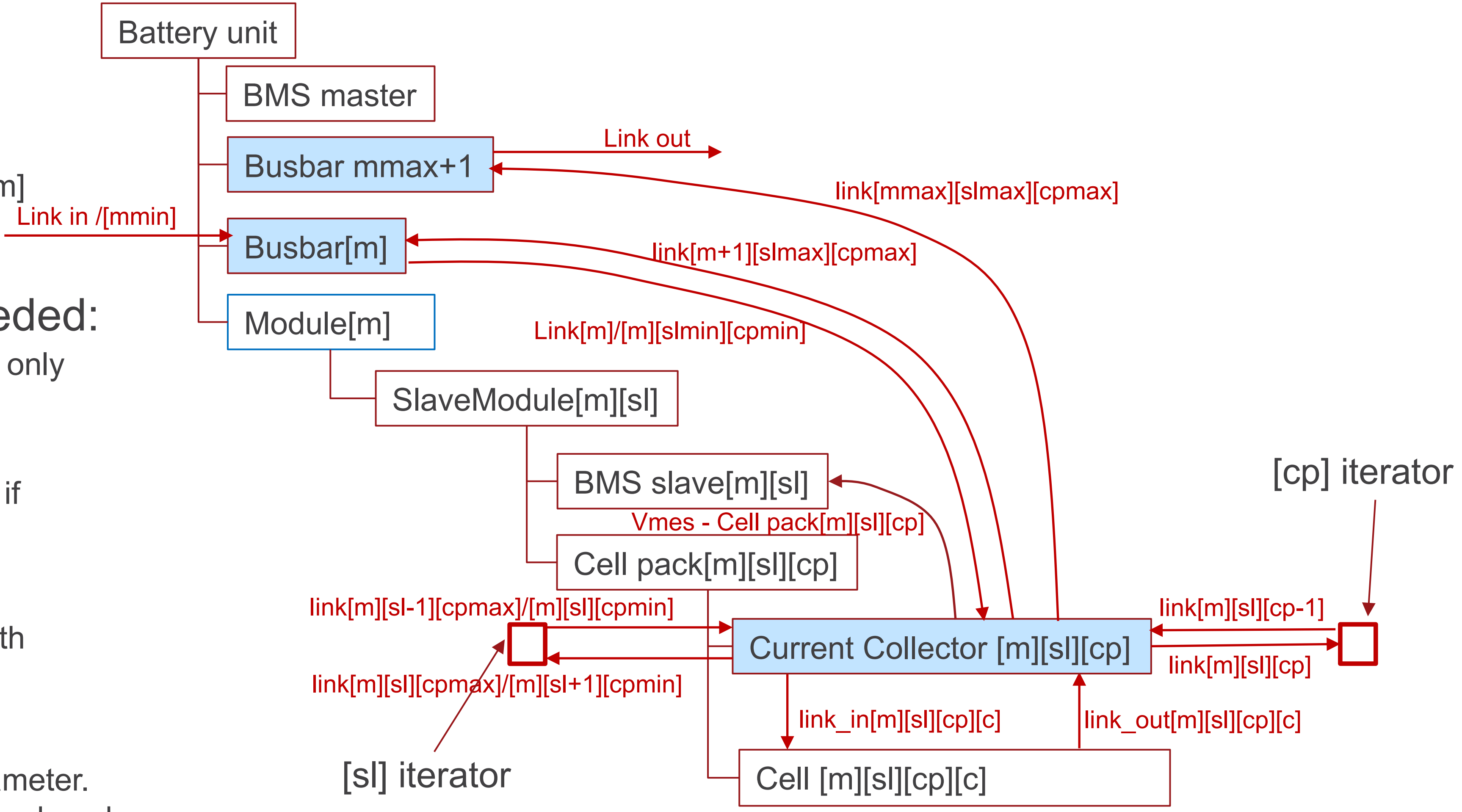
Some syntaxtic rules are needed:

« link[m][slmin][cpmin] » does exist if and only
if: sl == slmin
cp == cpmin

« link[m][sl][cp-1] » does exist if and only if
cpmax ≥ cp-1 ≥ cpmin

« link A/B » is a link from an object with parameter configuration A to an object with parameter configuration B

Iterator means the input and output flows correspond to each other w.r.t some parameter. The interest here is to check that every produced flow is consumed and conversly.



Limits of Absolute Indexing

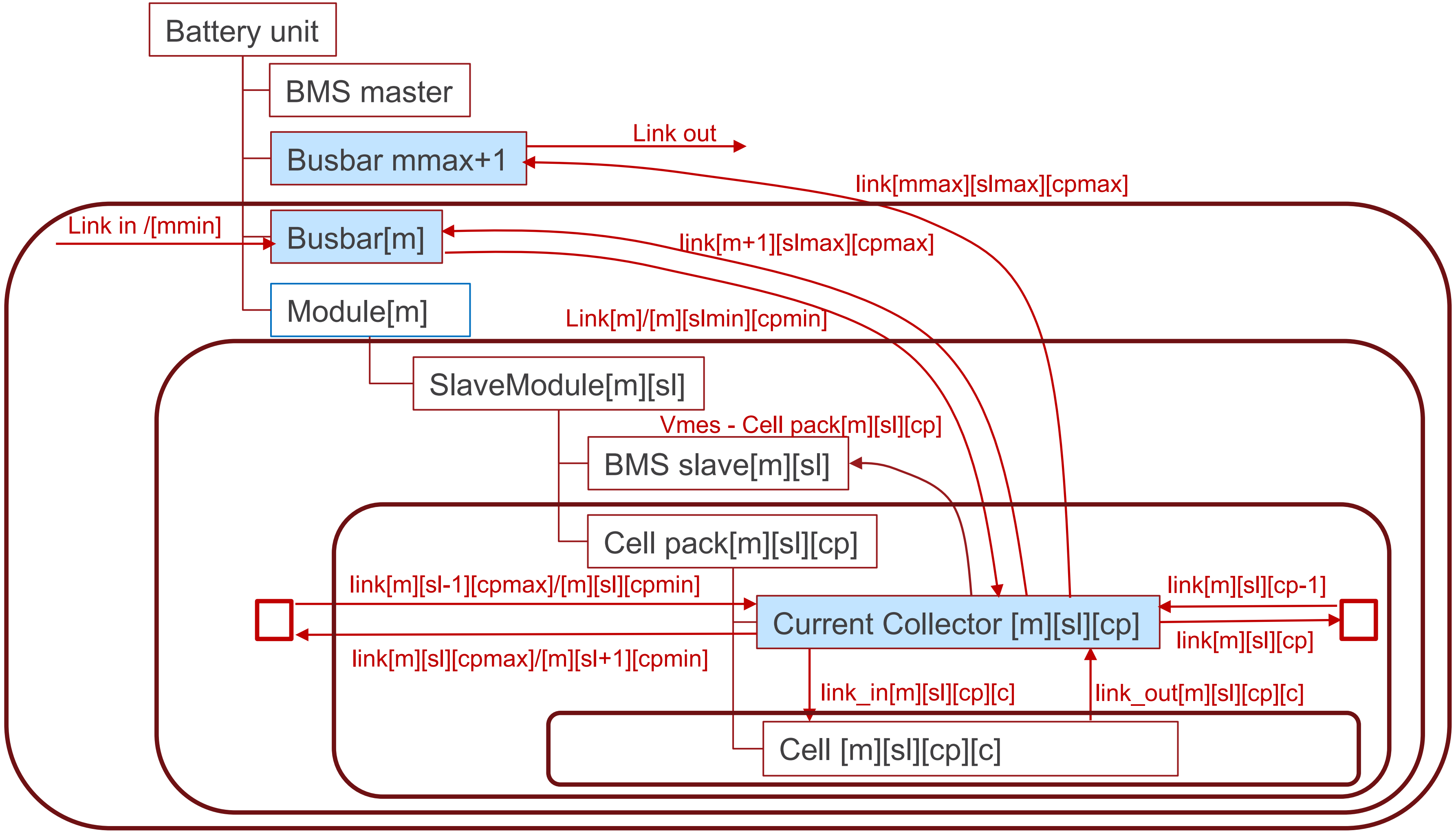
- Objects and flow identifiers get complex
  - Many parameters
  - Cumbersome naming

e.g for a tree structure:

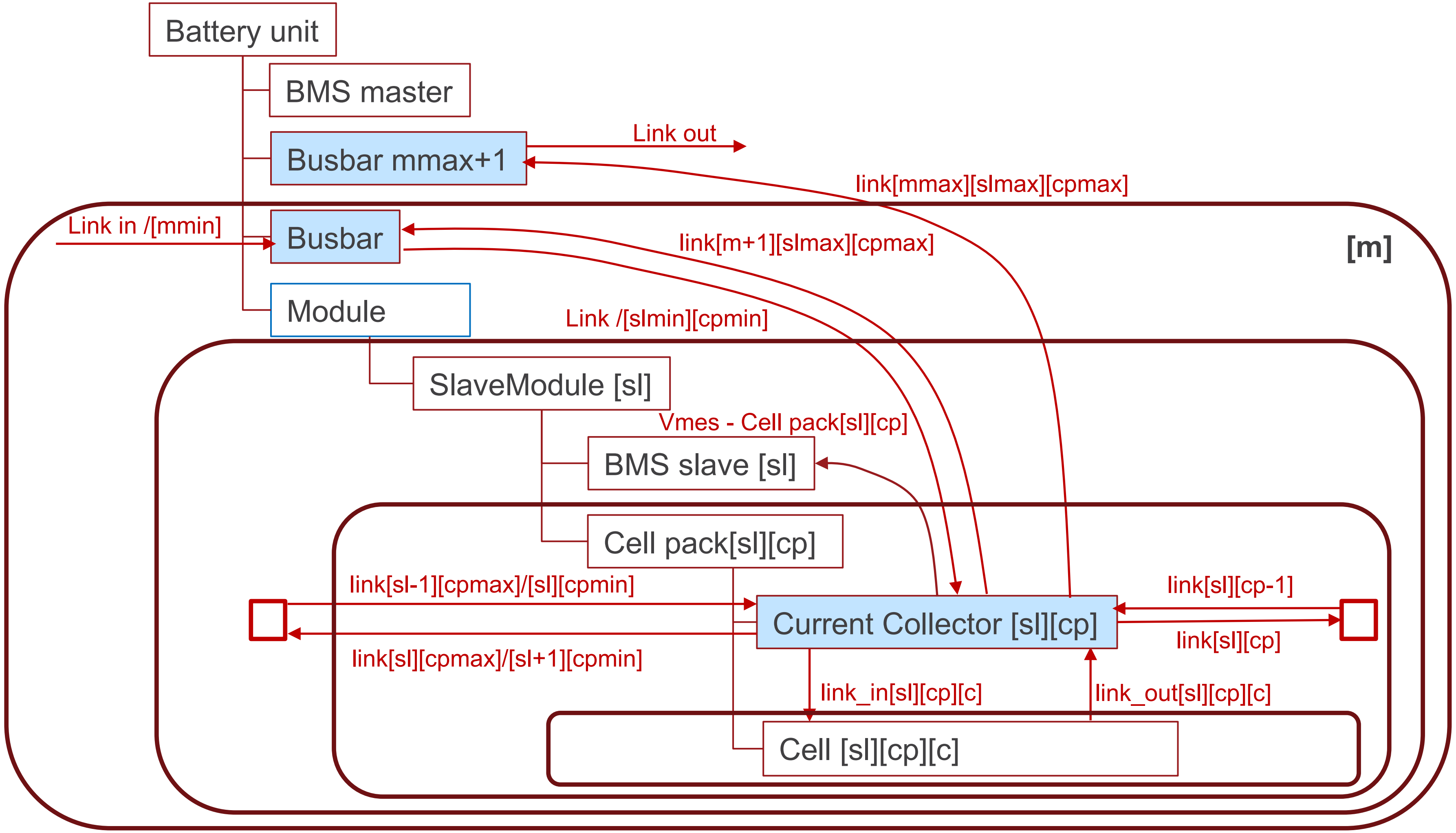
- Difficult to manage for highly complex systems
  - Lung model should cope with more than 20 bronchial splits leading to more than 20 parameters.

Can we find a more powerful syntax? We think so

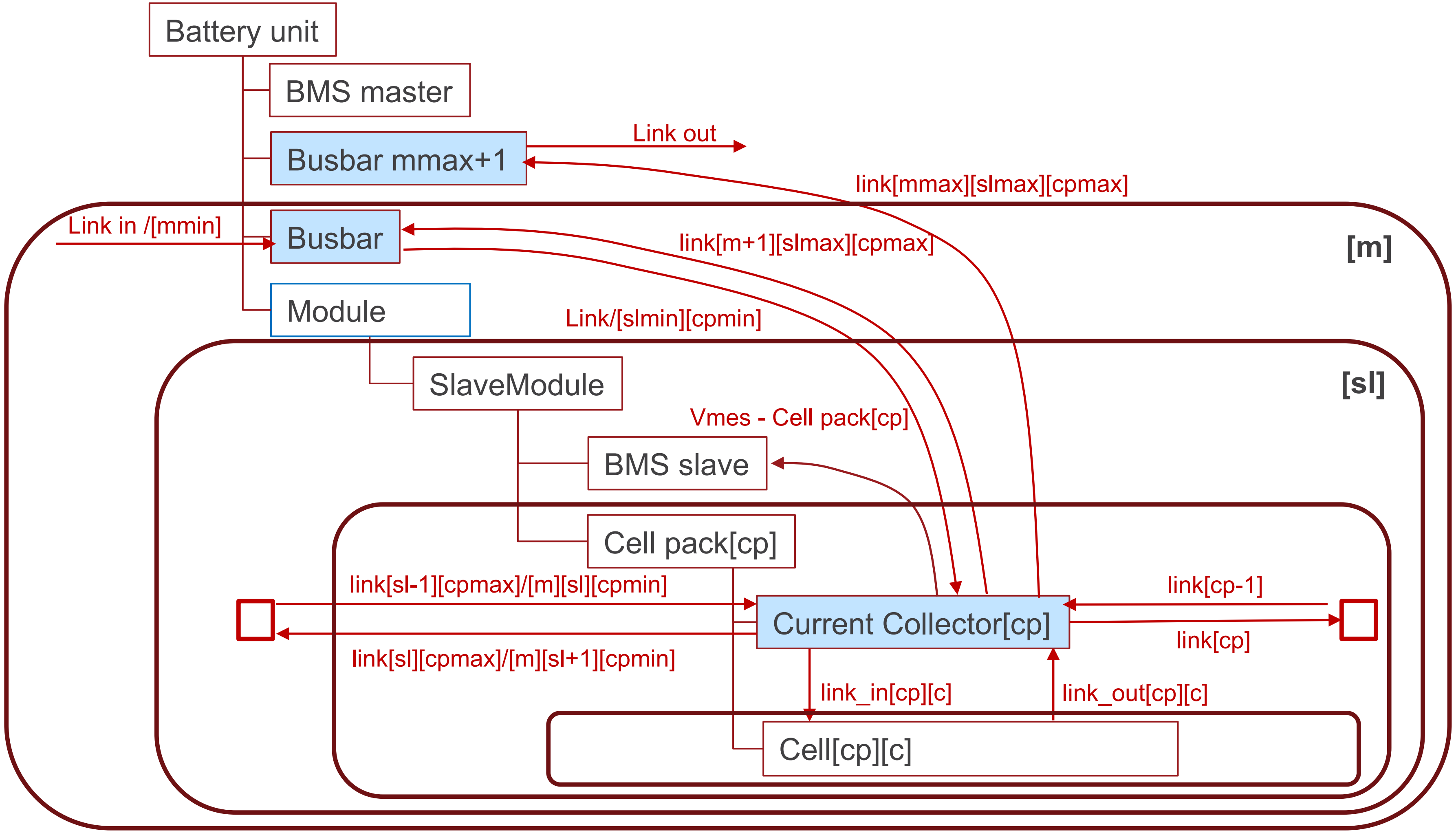
Introducing Parametric Containers



Introducing Parametric Containers



Introducing Parametric Containers



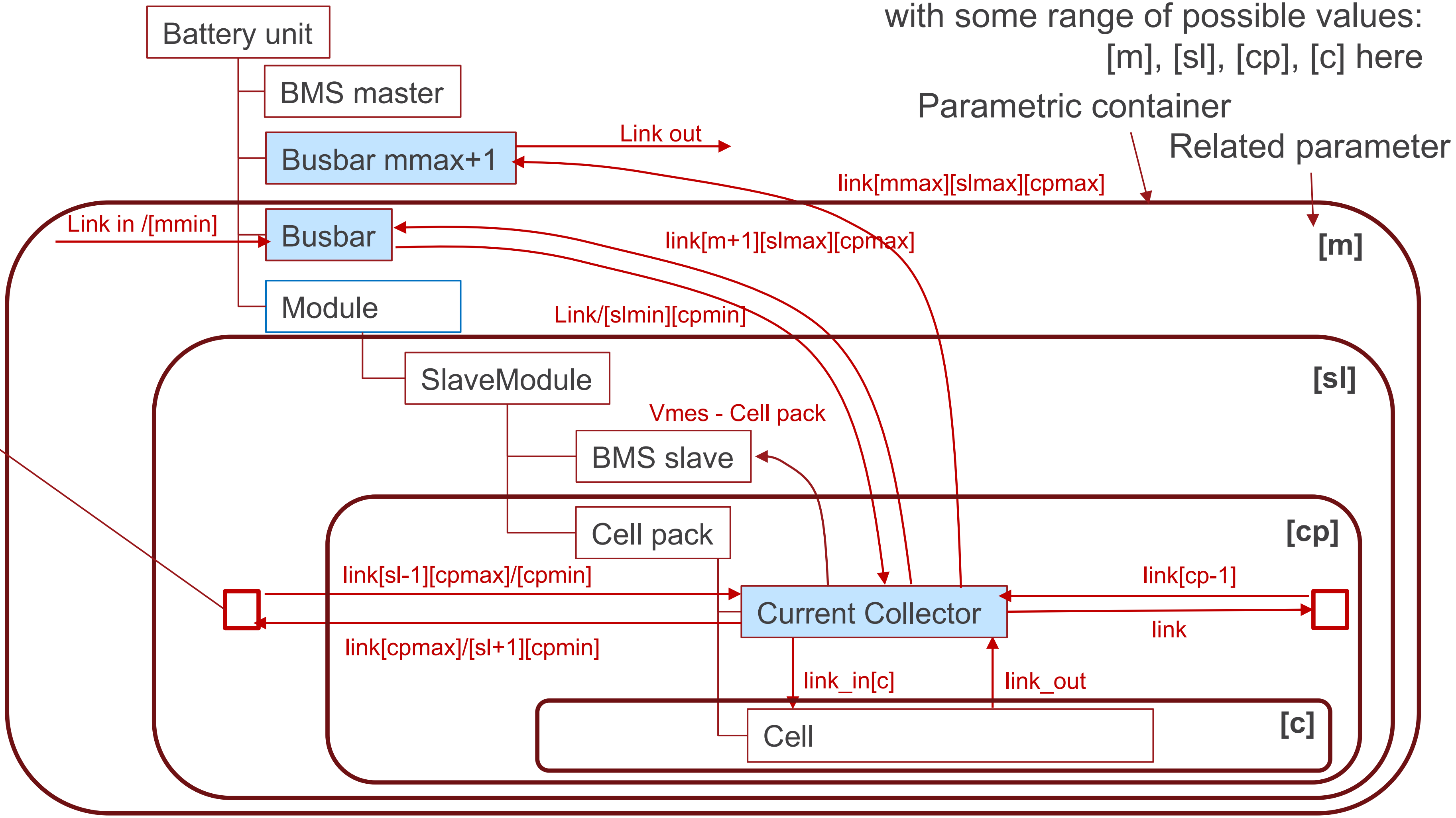
Introducing Parametric Containers

Each container relates to a parameter with some range of possible values: [m], [sl], [cp], [c] here

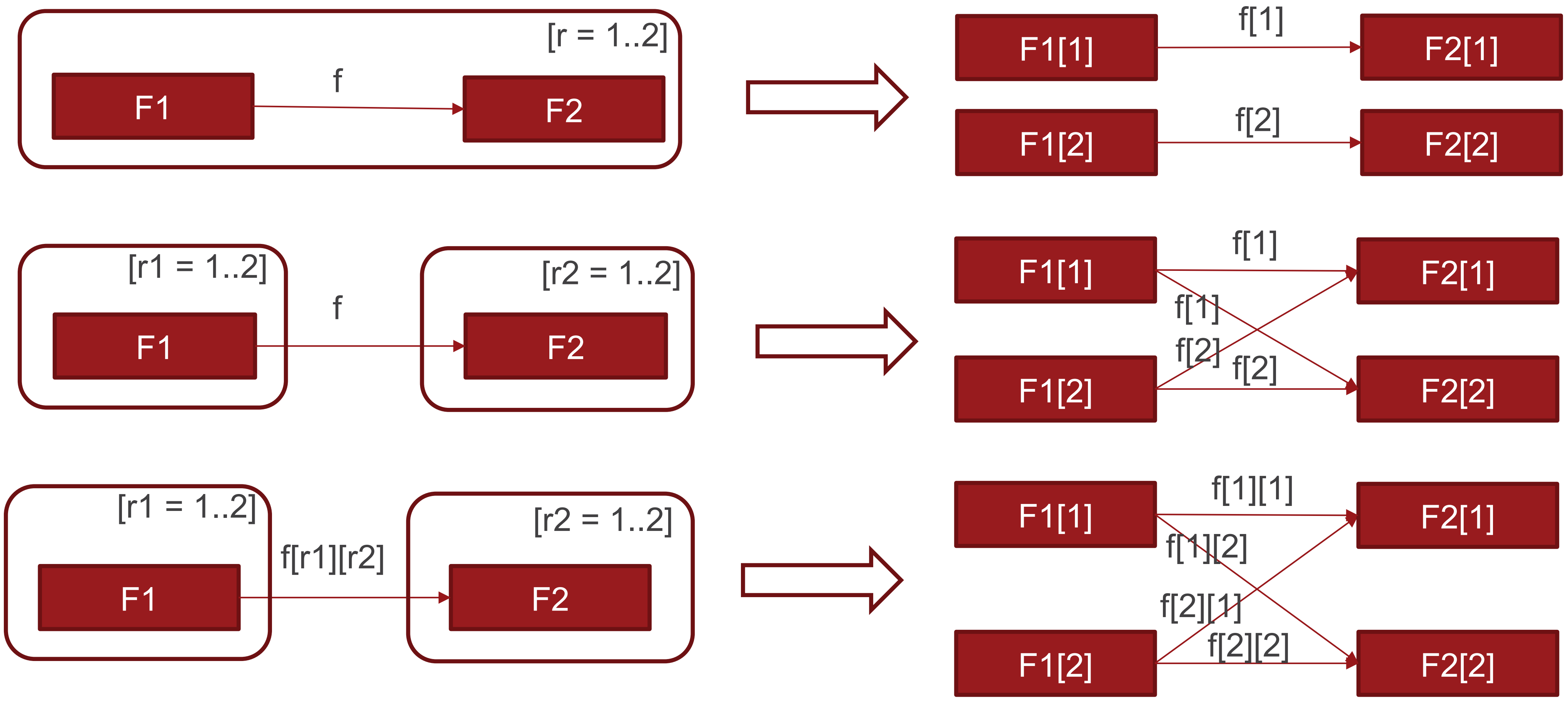
Put the iterator where it belongs

Any object inherit all parameters over it, except in case parameters are explicitly written

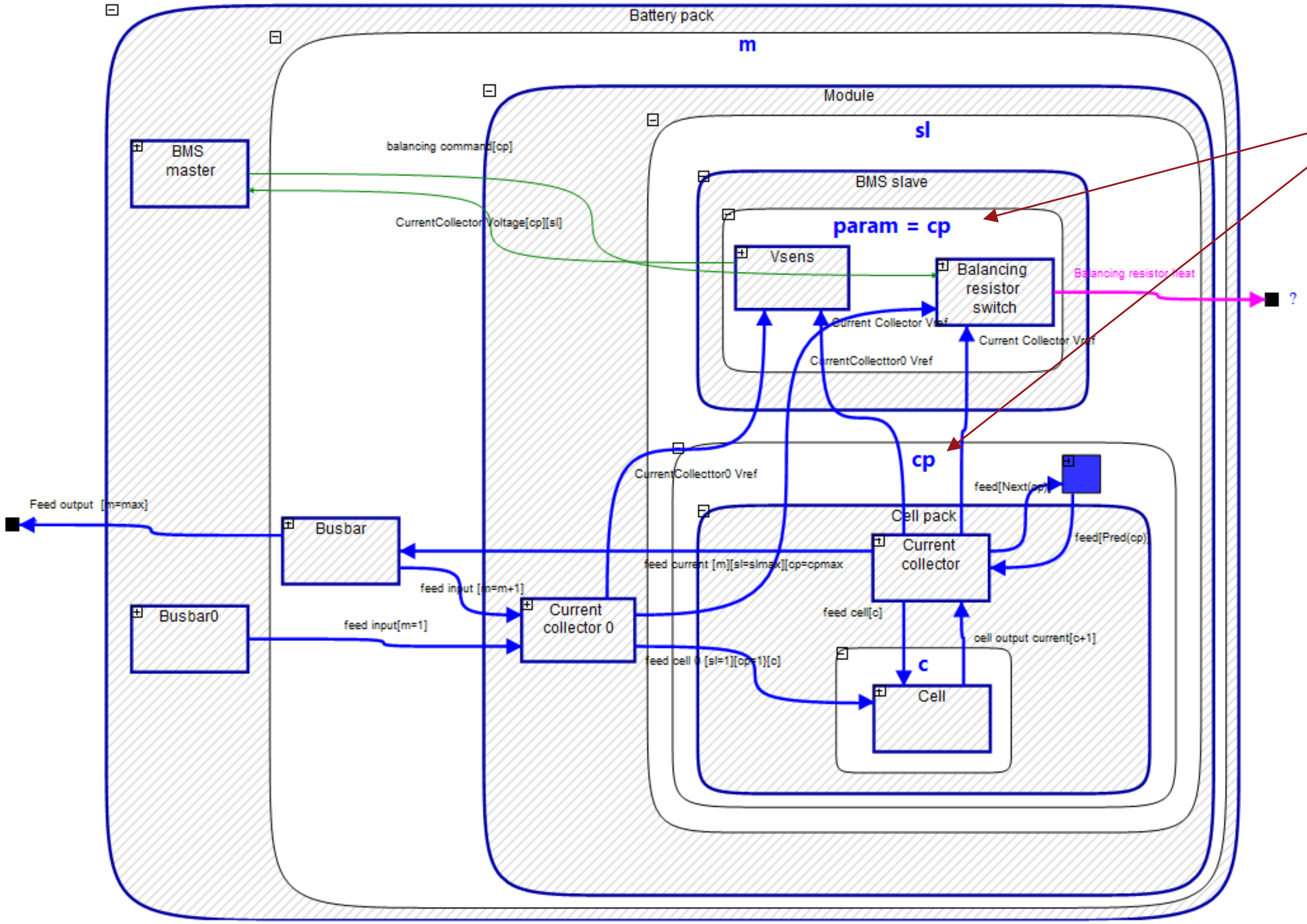
Any flow gets parameters according to its production first



Learnings: Applying Notation to Redundancy Strategies



Learning: Parametric Containers with Flows



Nothing prevents from finding the same parameter container with several occurrences

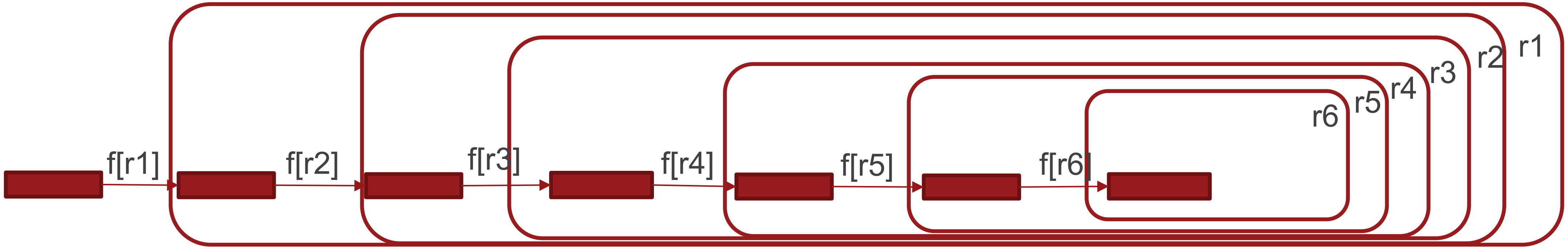
Developing a data model for our battery example with arKItect© by Knowledge Inside SAS

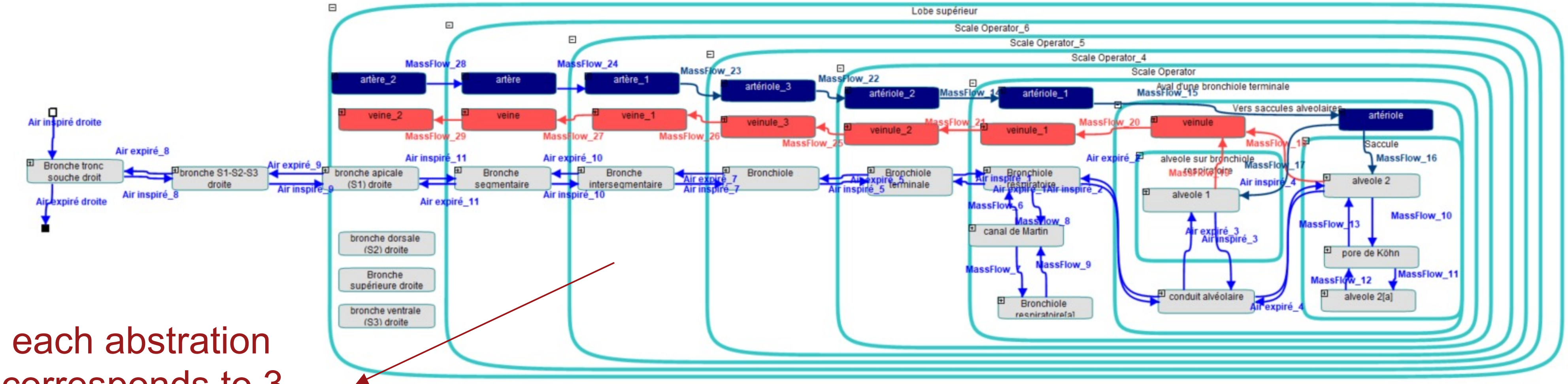
NB: This model is supposed to be 20.000 objects and 100.000 interfaces large

The number of layers and total number of avioli is daunting

Modeling the Human Lung

Learnings: Applying to Tree Structures





Blood with CO2

Blood with O2

Air

Here each abstration step corresponds to 3 decompositions layers

Partial model of a lung modelled with arKItect© by Knowledge Inside SAS

In this presentation, we have merely started to formulate the problem.

Conclusion and Path Forward

Parametric Containers and SE Artefacts

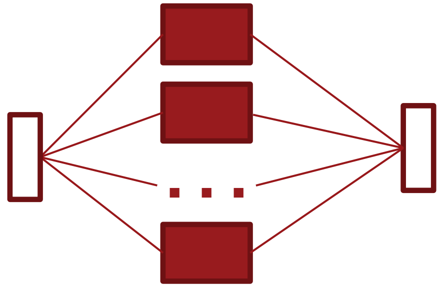
- The Parametric containers are part of the system view or solution view. By system here we mean both a functional and organic concept.
- Requirements may apply to a particular instance or to a set of instance.
- Usually we think of having at least two distinct views:
  - Architecture view – the one we discussed previously
  - Requirements breakdowns structure – mainly for the purpose of traceability between requirements applied at different system levels including traceability w.r.t external requirements.
- Requirements should probably inherit parameters of the systems on which they are allocated. They possibly should be allocated with specific(conditional) parameter values as well.

Conclusion

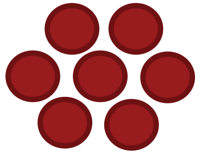
- Parametric Container seem to be a pretty aesthetic approach for modeling faithfully systems with a recursive structure using only a logarithmic number of objects in the model.
- We tested this approach on different case studies. It allows lowering the complexity of the system for the system architect and allows to present a very compact holistic system view.
- Minimizing the number of views for a system description is for us a very strong indicator as it simplifies the topic both for the author and for every user of the result.
- The concept of solution may introduce geometric concepts (which is very natural). The concept of neighbourhood of a parameter instance depends on the geometric concept.
- The approach fits very well with a modeler. We simply introduce a new category of pervasive containers w.r.t. a classical Systems Engineering data model. Instanciation of parameters in functional chains is a must.
- It's clear how to specify a generation from the system model toward domain specific modeling tools afterward: e.g based on matlab, modelica….

Ongoing and Further Works

- A parameter angle may depend on it's parent parameter values.
- Available functions on parameters instances need to be clarified, min and max may not exist in case parameter range is not ordered
  - **This is where geometric concept is needed and part of the concept of a solution**
- Possibly, we could imagine patterns of patterns: in the case of the lung, some levels of decomposition can be gathered because « they decompose the same way ». This leads to a higher complexity (parameters as patterns of subparameters) but more compact representation
- In the modeling approach, it is possible and important to generate automatically chains unfolding the parametric model for some sets of parameters values. e.g. you are interested to see what happens at the border of two modules of the battery, want to check side effects
- This approach allows defining an unambiguous naming of all objects in the product.

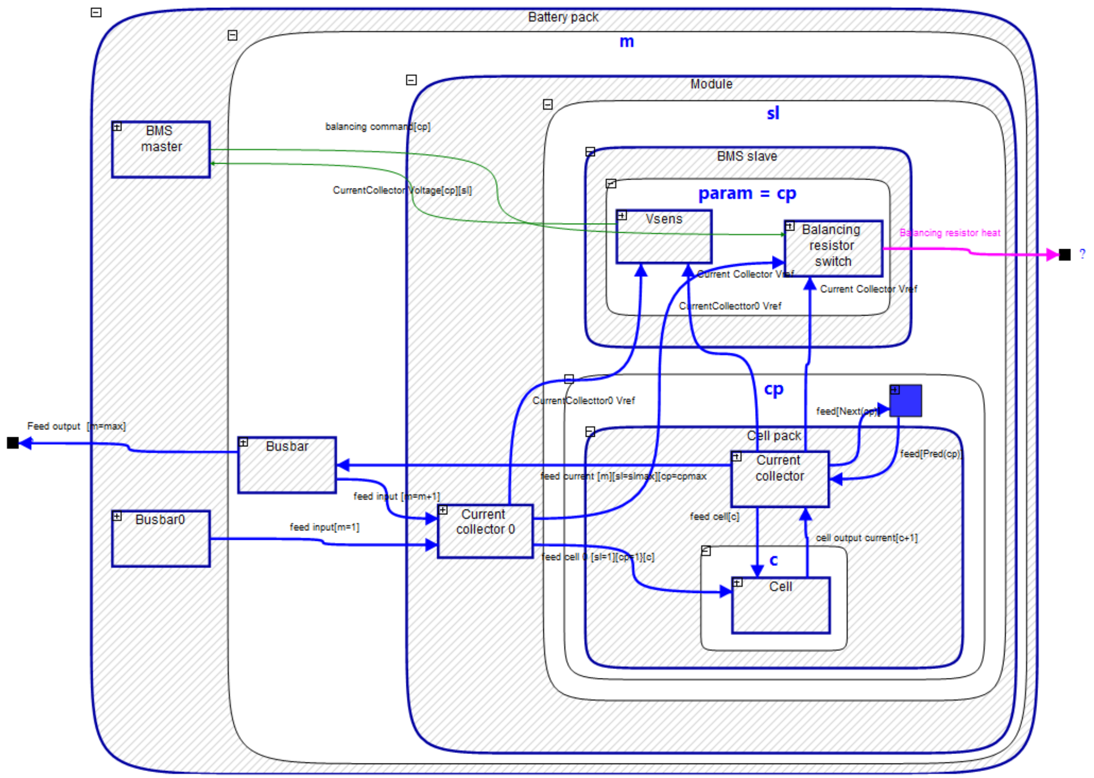


List of cells in parallel:
Min, max, +1, -1



Set of tubes in a cooling exchanger
Numbering rules and functions tbd

Thank You


Battery pack
m
Module
sl
BMS master
balancing command[cp]
CurrentCollectorVoltage[cp][sl]
BMS slave
param = cp
Vsens
Balancing resistor switch
Balancing resistor heat
?
Current Collector Vref
CurrentCollecttor0 Vref
cp
CurrentCollecttor0 Vref
feed[Next(cp)]
Cell pack
feed[Pred(cp)]
Feed output [m=max]
Busbar
Current collector
feed current [m][sl=slmax][cp=cpmax
feed input [m=m+1]
Busbar0
Current collector 0
feed input[m=1]
feed cell[c]
cell output current[c+1]
feed cell 0 [sl=1][cp=1][c]
c
Cell

Q&A

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www.incose.org/symp2022