Hierarchical CnC

Kath Knobe

Thanks to …

- Zoran Budimlić – Rice
- Nick Vrvilo – Rice
- Frank Schlimbach – Intel
- Milind Kulkarni – Purdue
- Gary Delp – Mayo Clinic

High level motivation

- Software engineering
- Hierarchical understanding
- Hierarchical optimizations
- Hierarchical mapping
- Reuse
  - Within a single app or from a library
  - Communicating runtimes
- Hierarchy is not only for computation but also hierarchical
  - Documentation, development, testing, debugging, checkpoint-continue, static & dynamic analysis, static & dynamic tuning, etc.

No assumption about the implementation

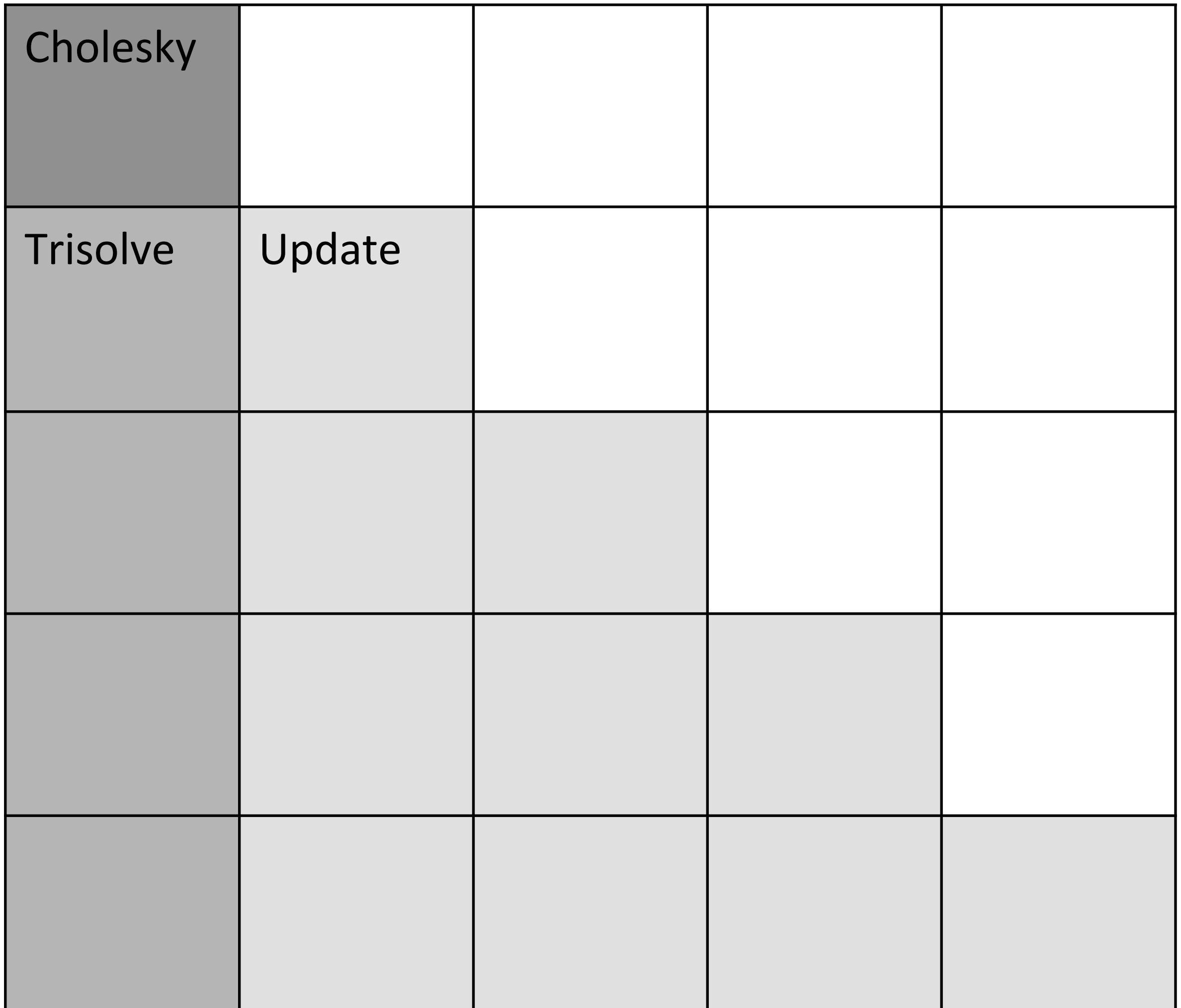
- Some languages know about arrays, lists, strings
- CnC knows about collections, graphs, tags
- We have a variety of different implementations of these
- Hierarchical CnC will also know about hierarchy
- We can have a variety of very different implementation of hierarchy
- Even the runtimes can be different at different places or levels in the graph

Outline

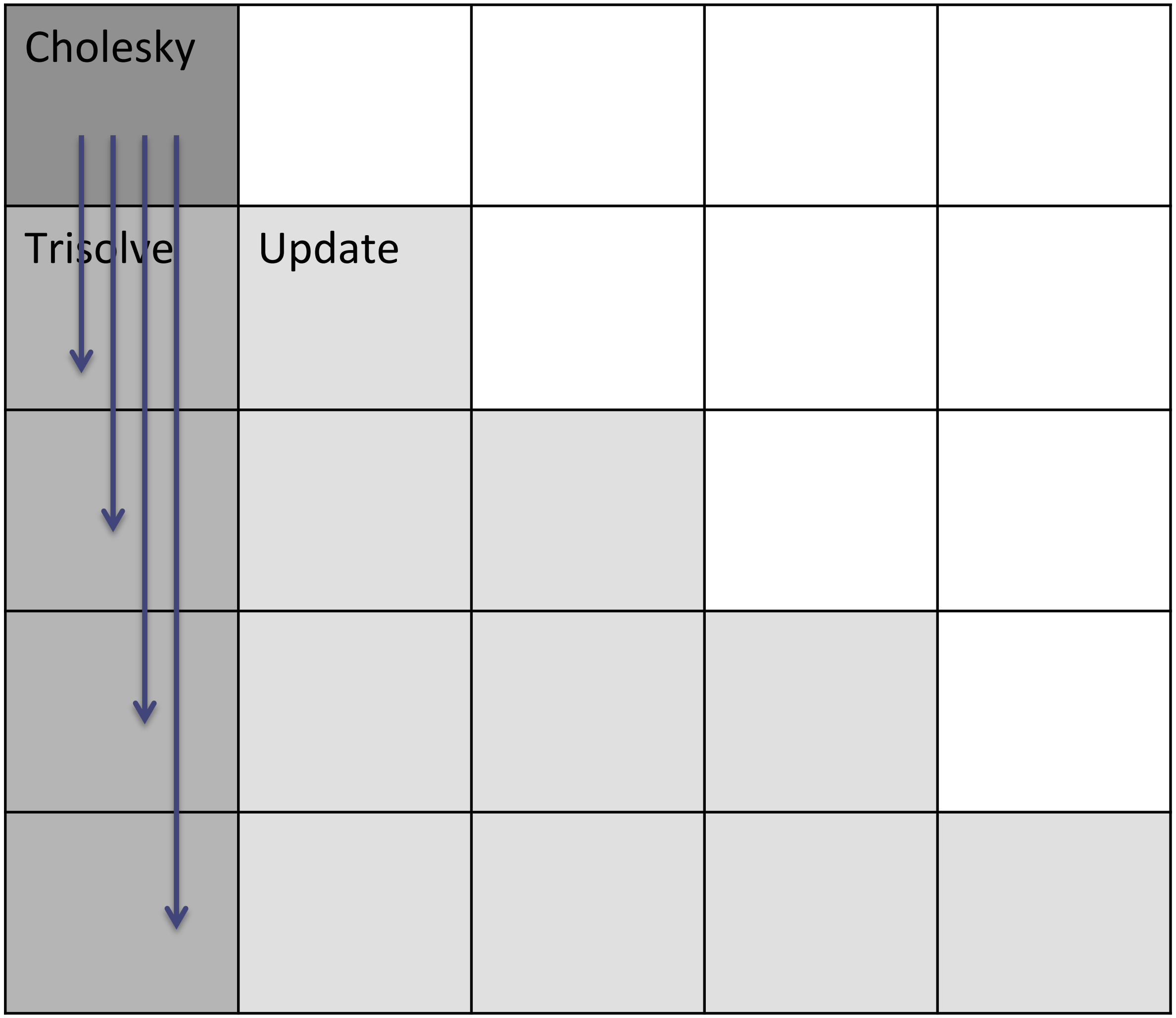
- Background via an app
- Introduction to hierarchy
- Constraints and optimizations

Background via an app

Cholesky factorization



Cholesky factorization



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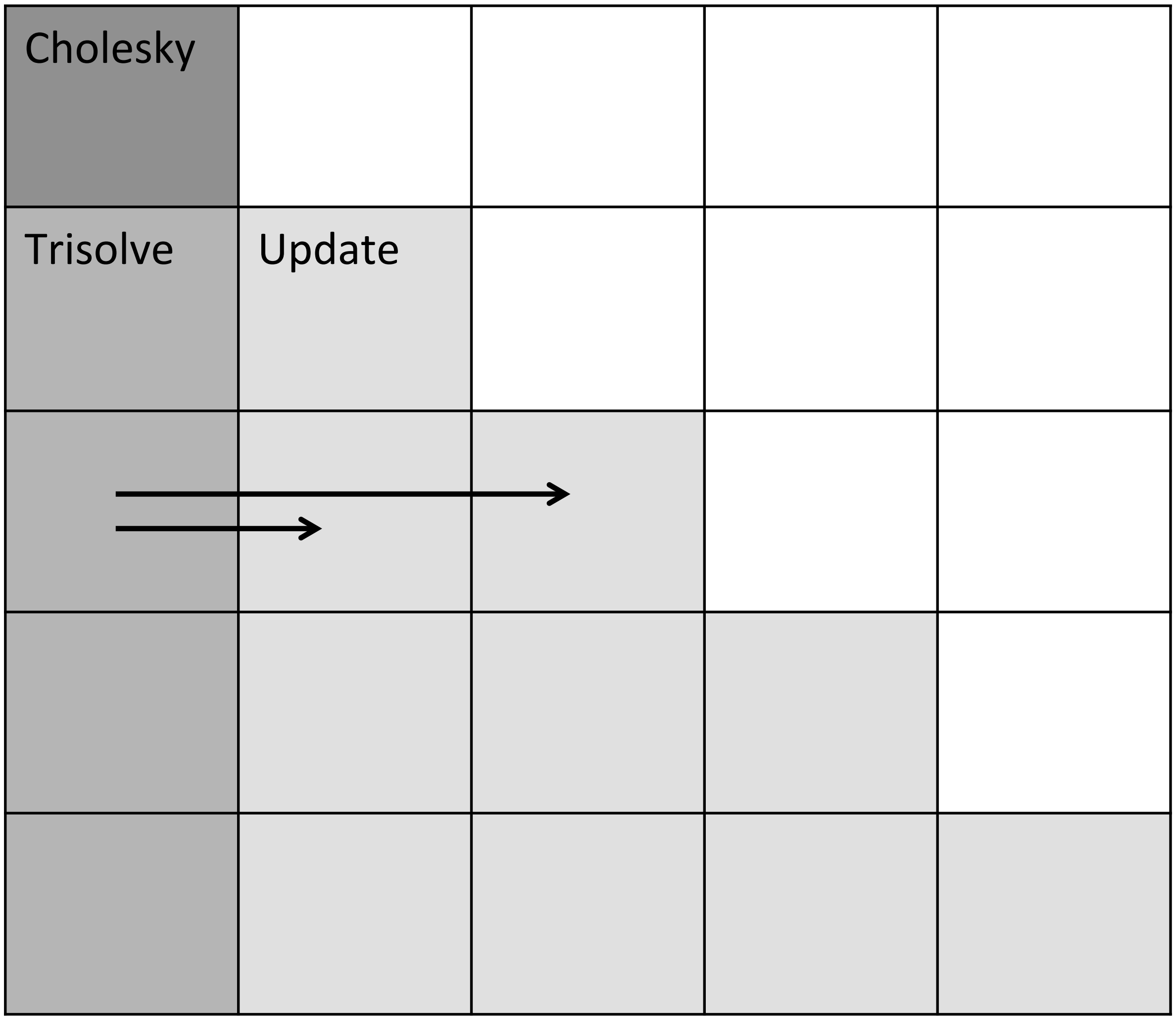

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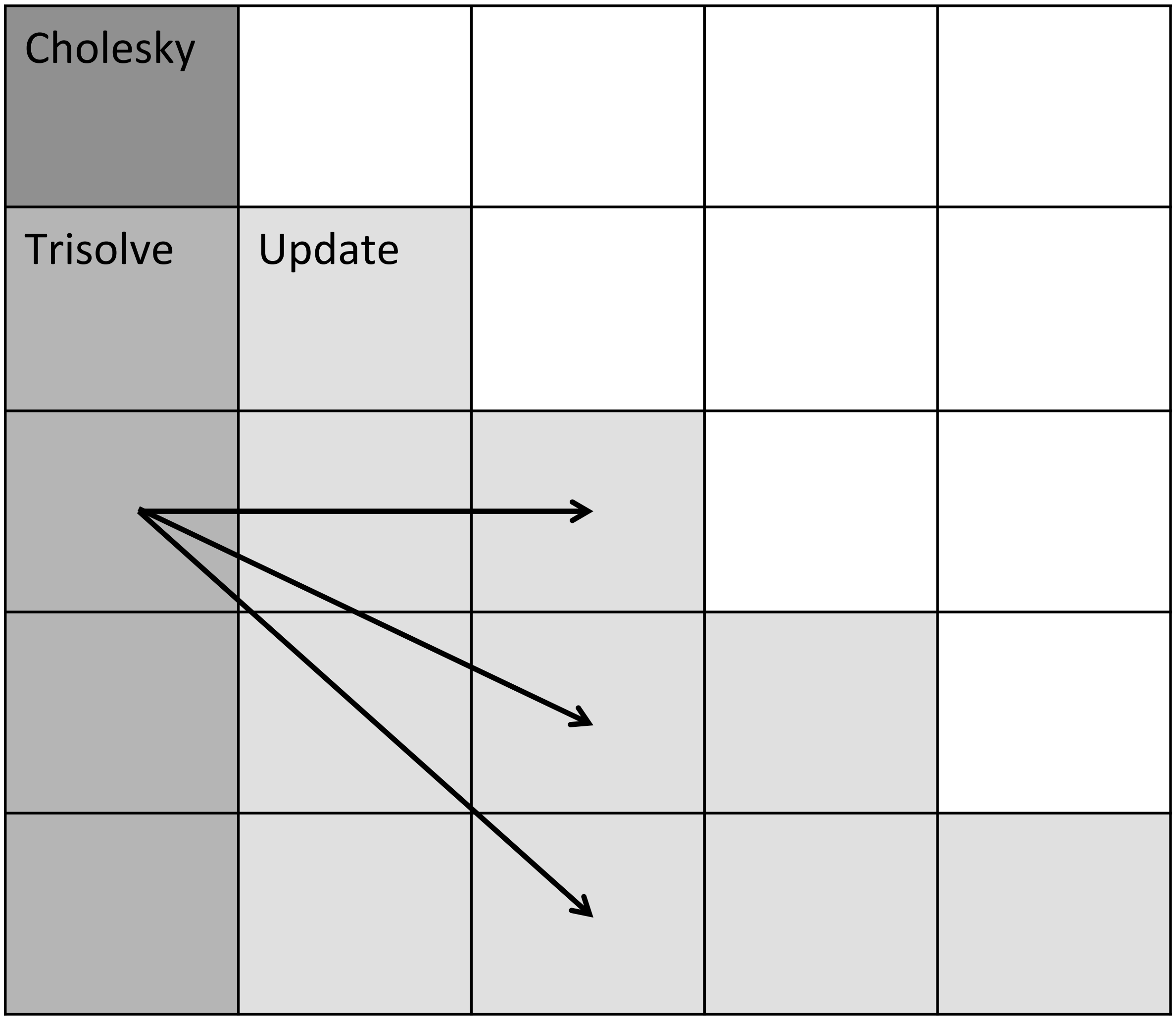

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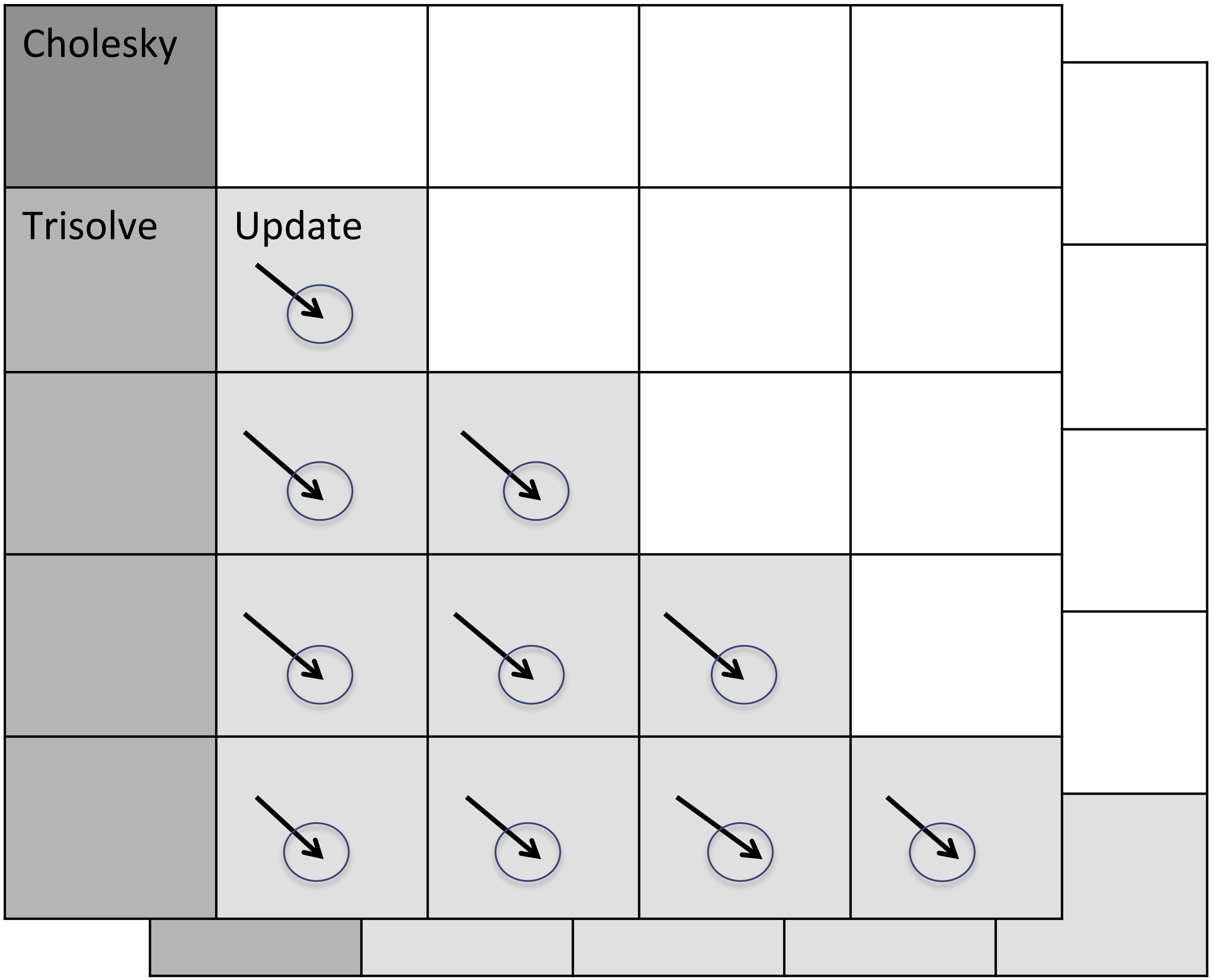
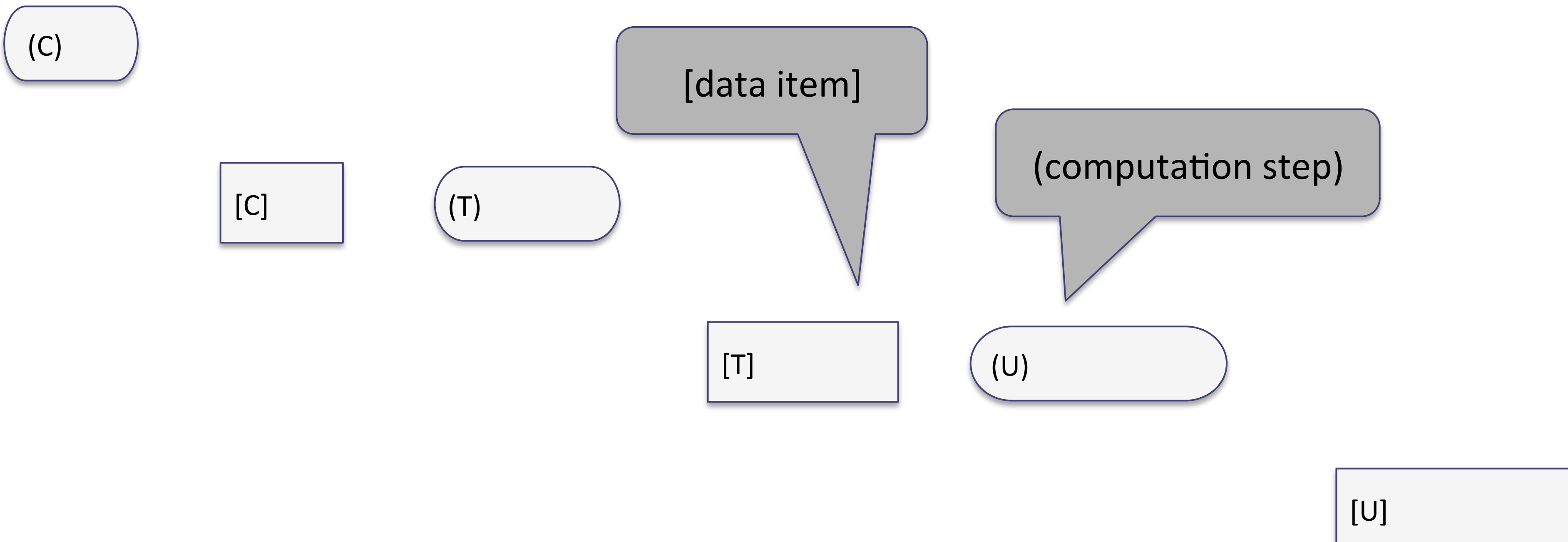


Cholesky factorization

Cholesky CnC graph spec



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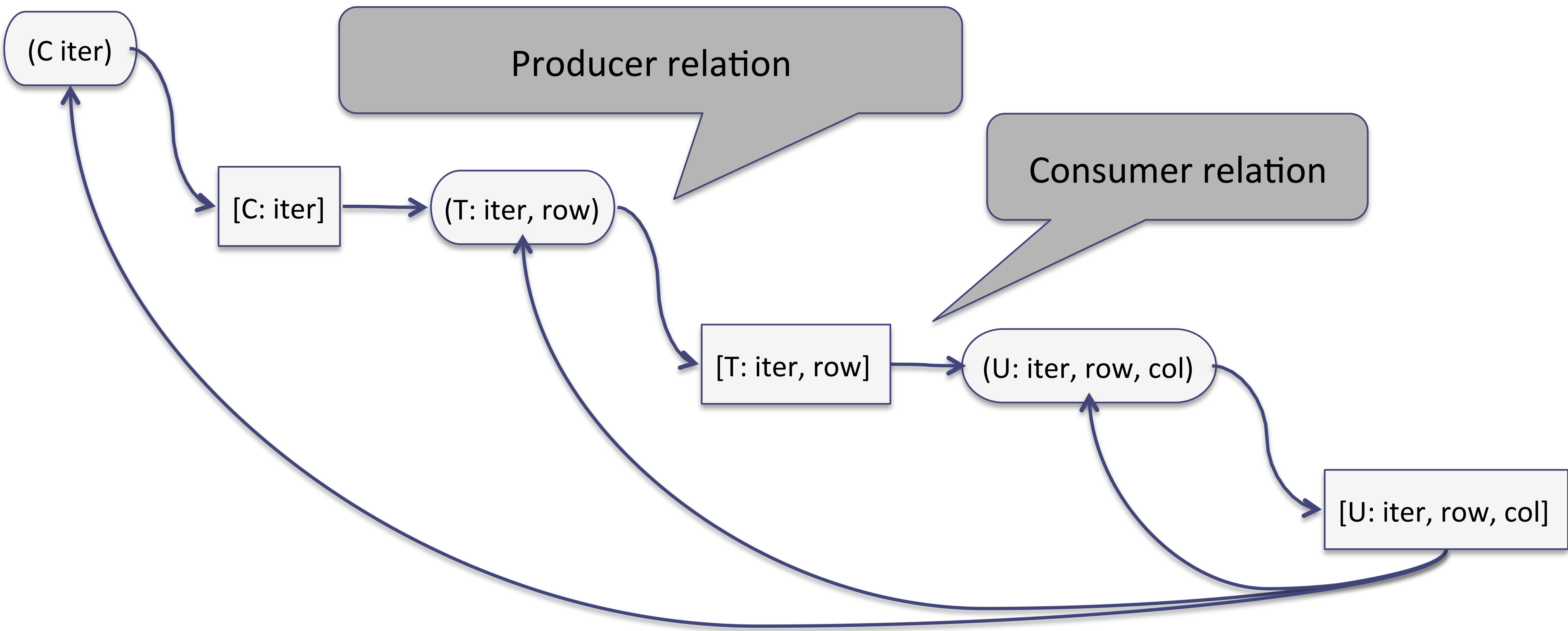

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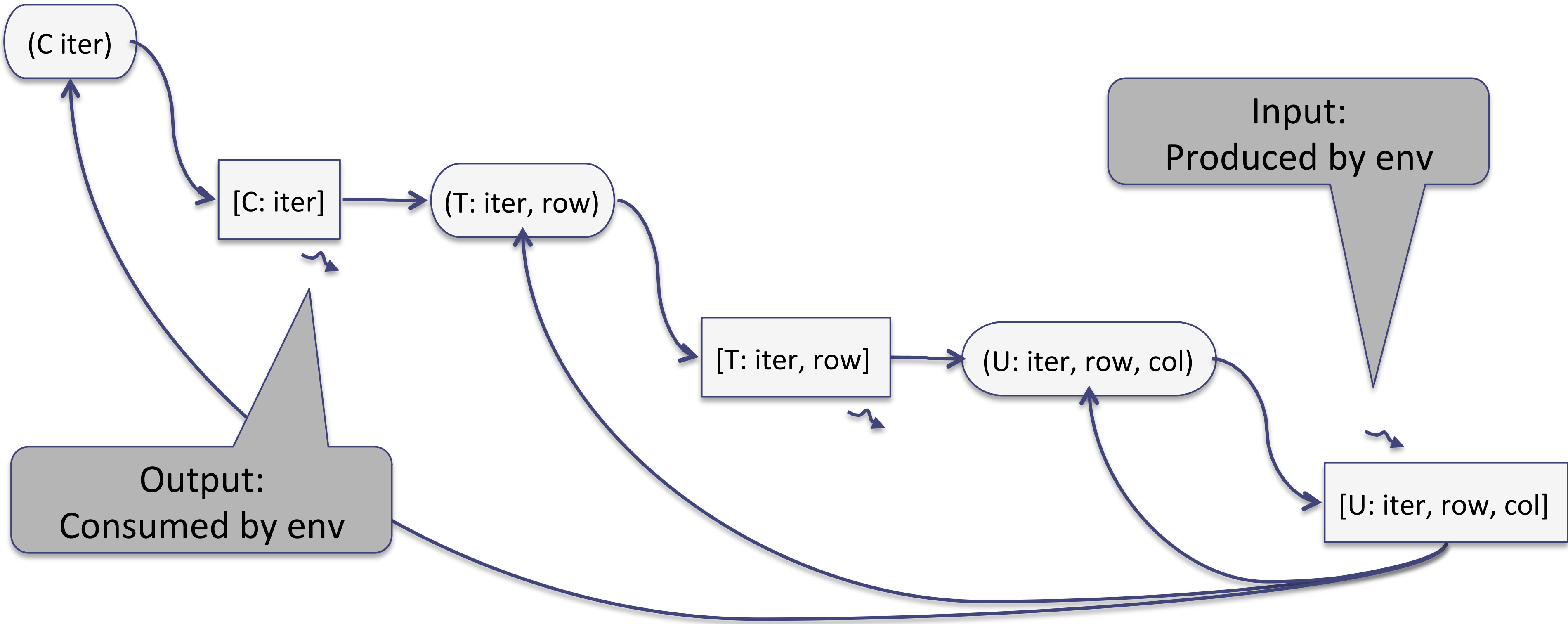

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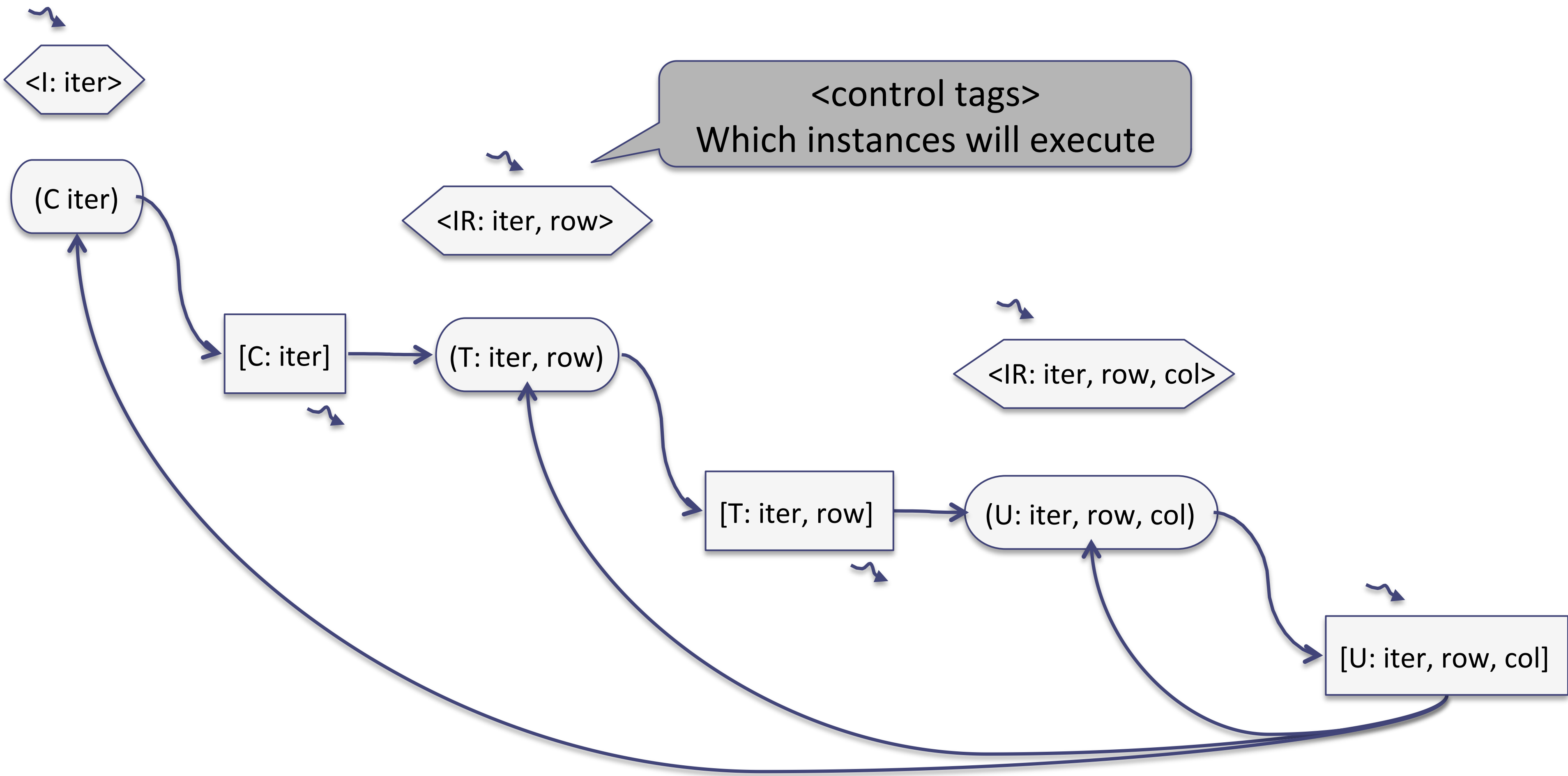

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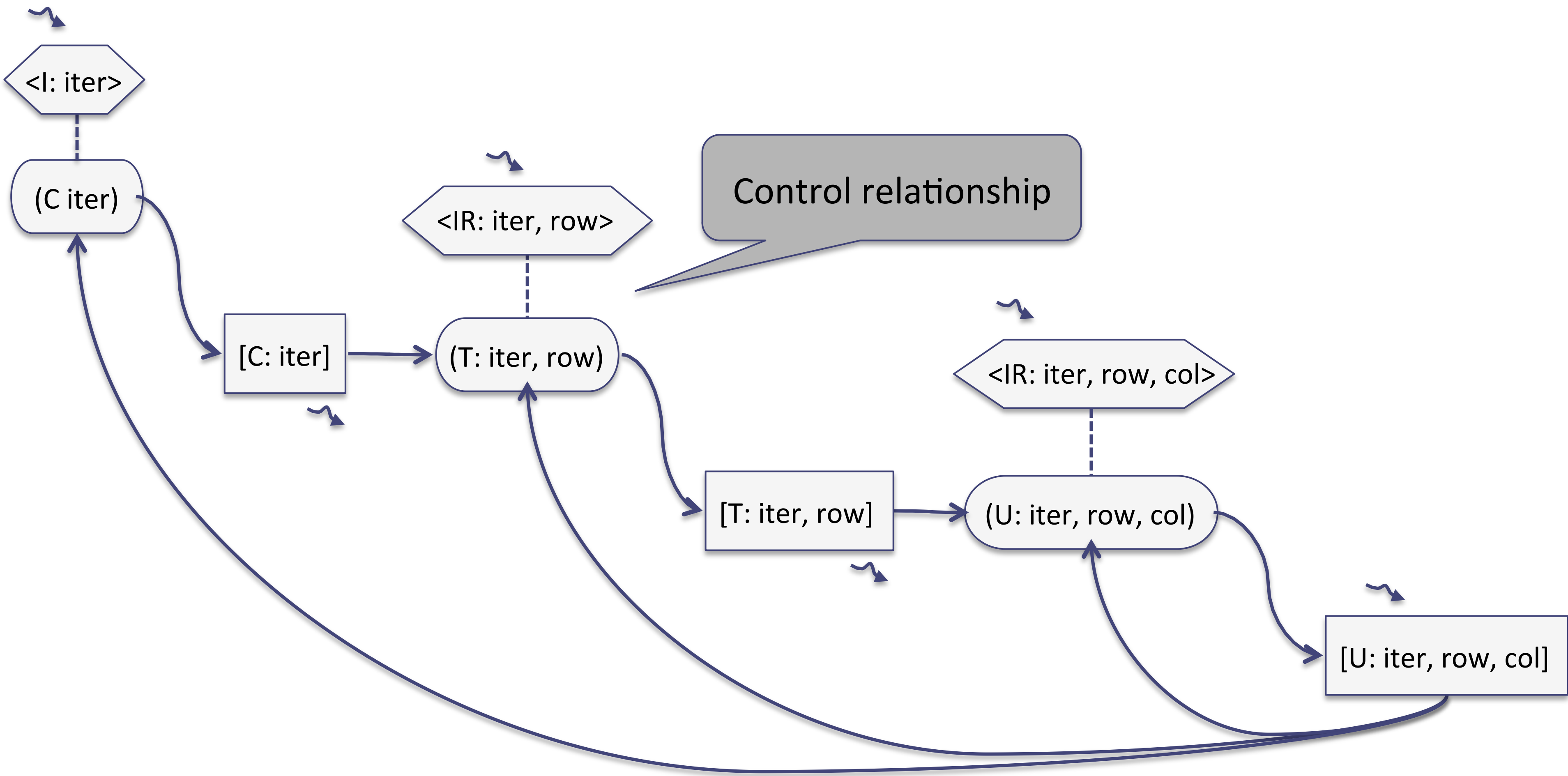
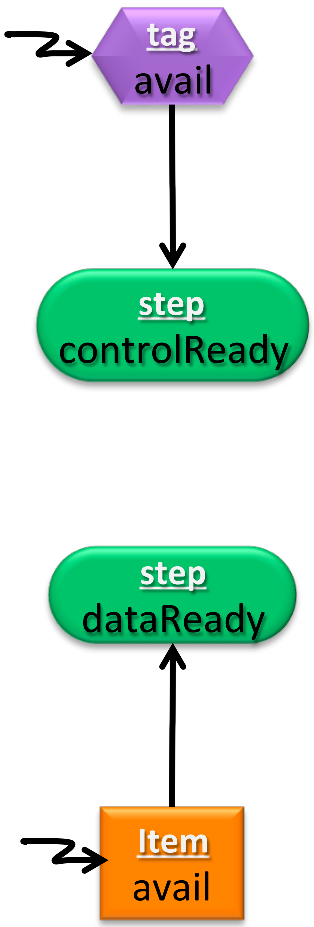


Semantics of CnC:
specifies a partial order of execution



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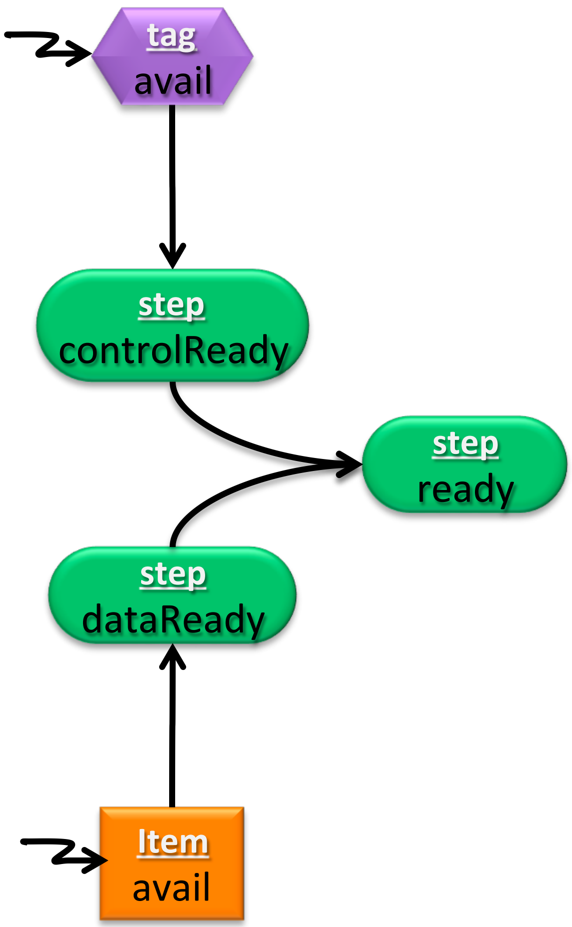

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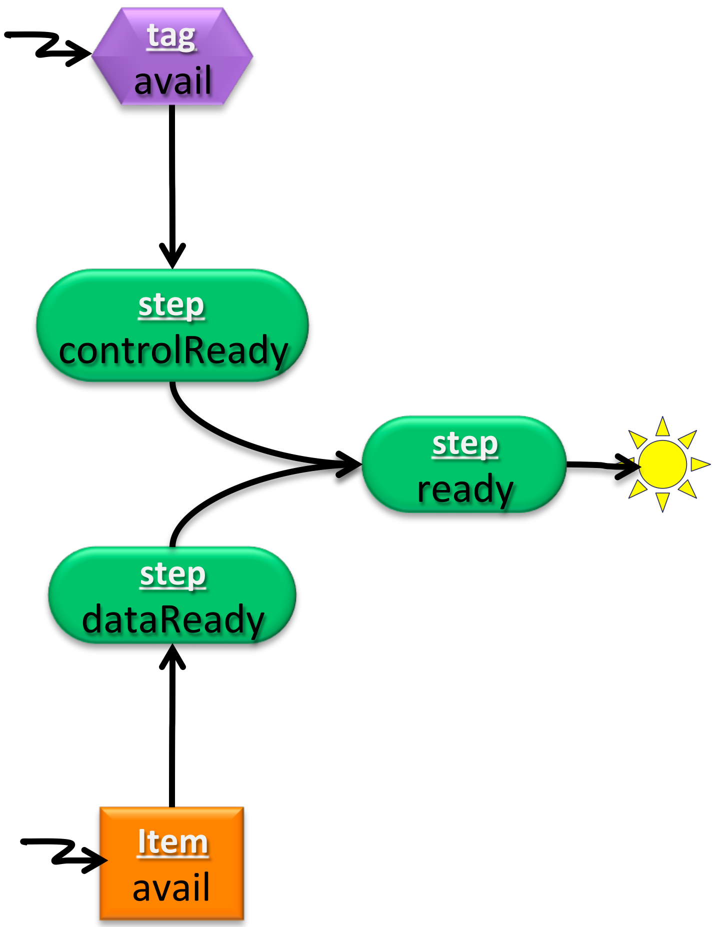

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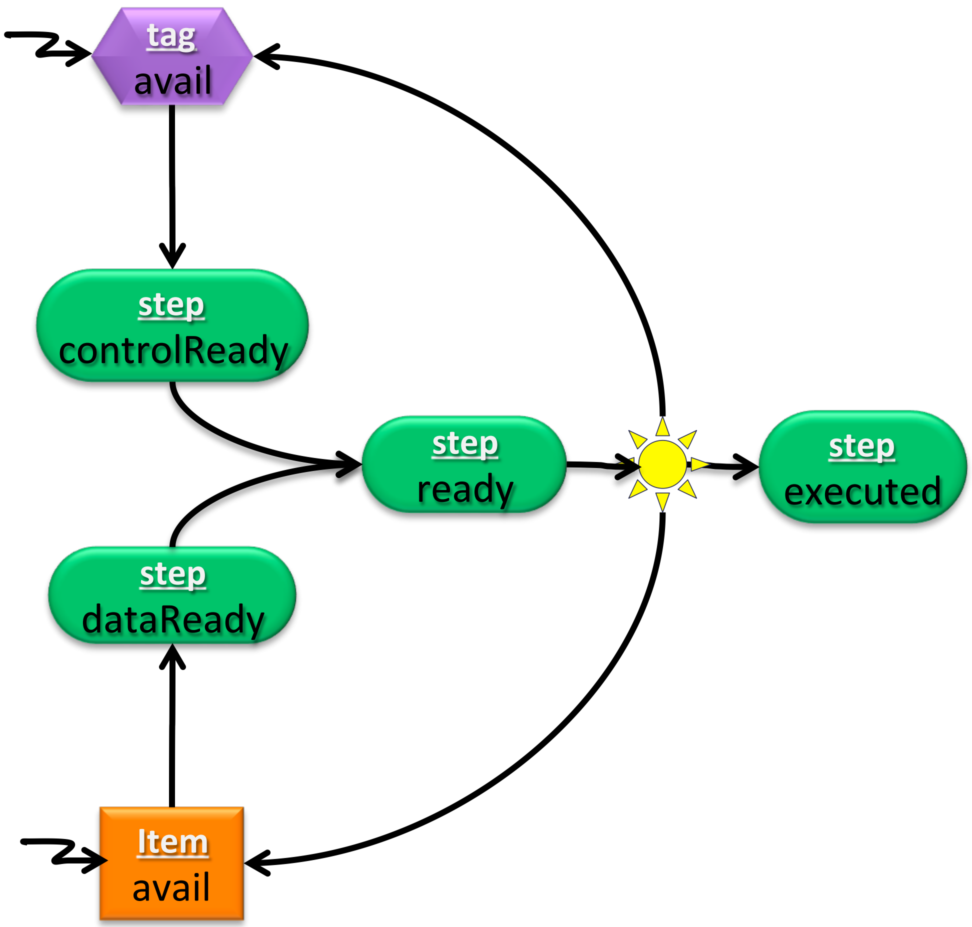

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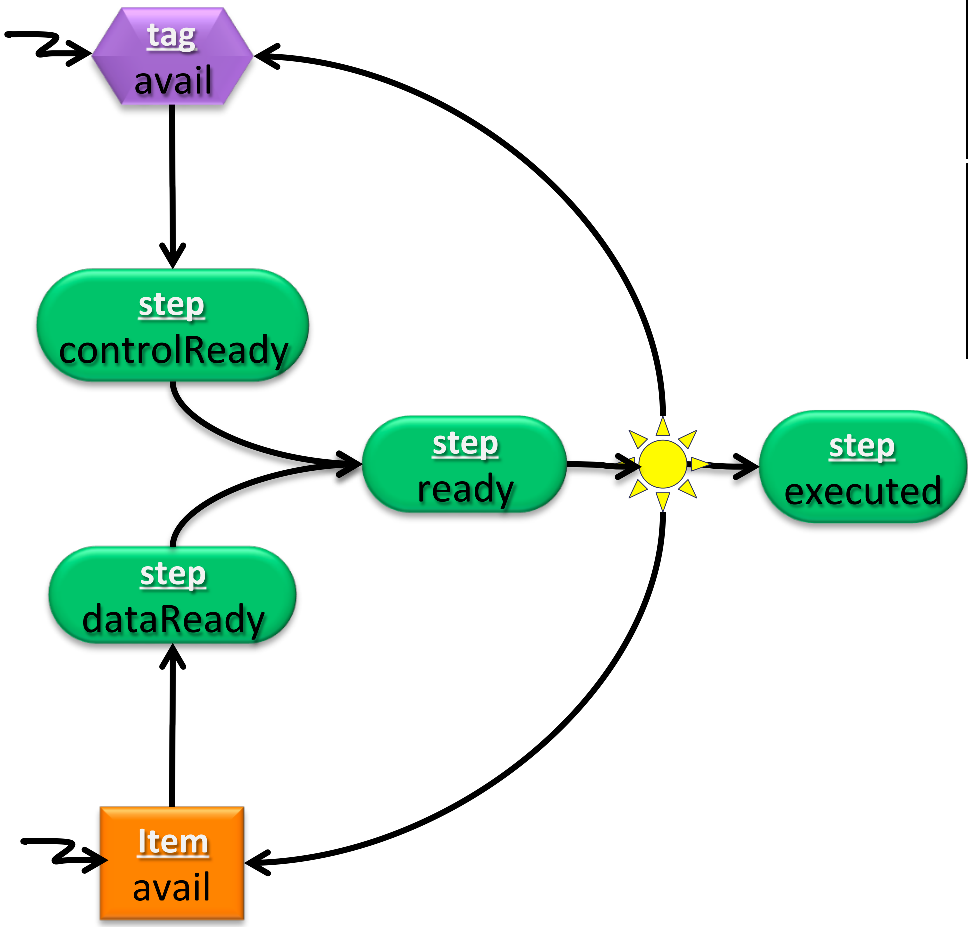


Termination:
- No step is executing
- All ready steps have executed
- All inputs have arrived

Clean termination:
- Termination
- All control-ready steps have executed

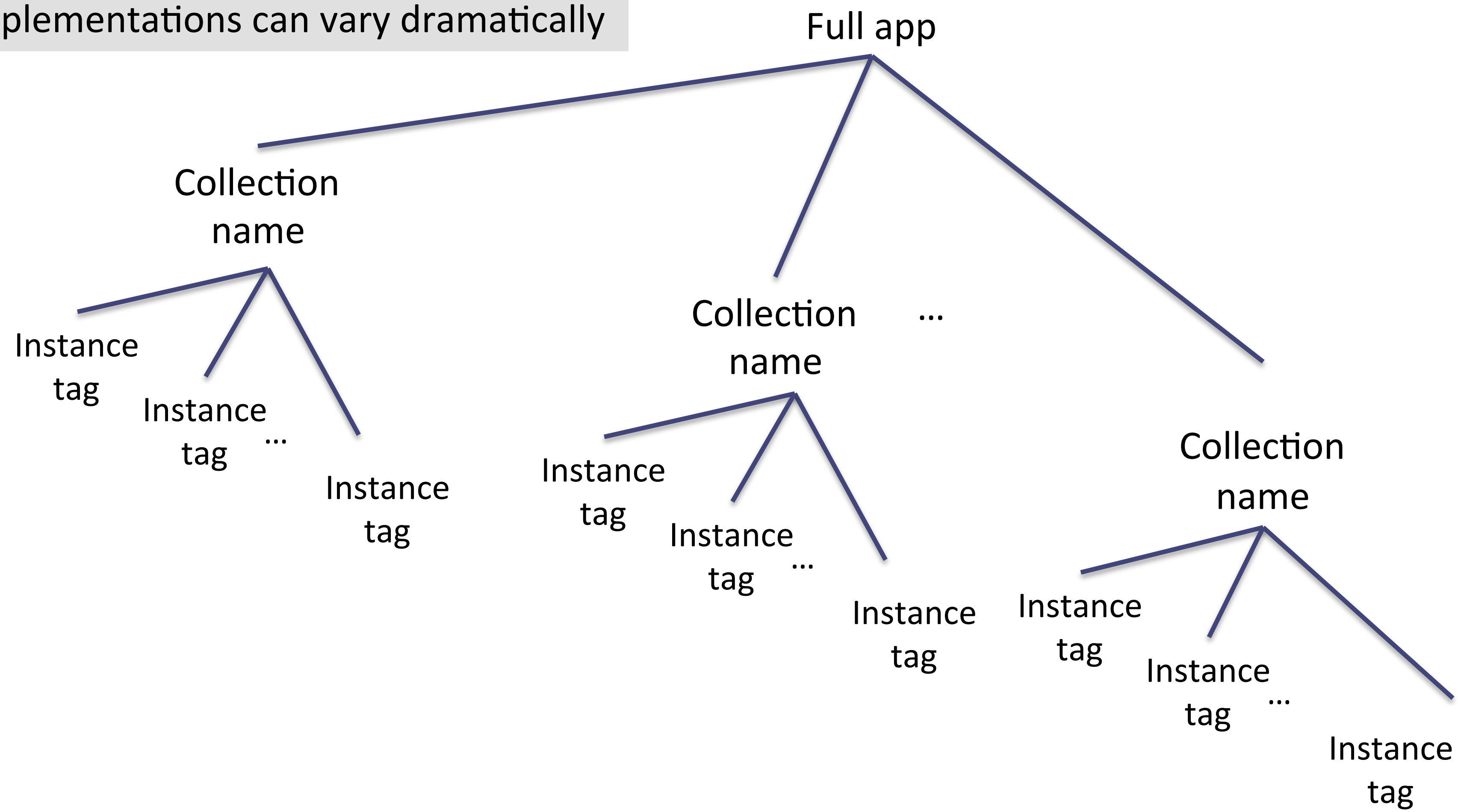
Introduction to hierarchy

Basic idea

- Every level appears to be a normal CnC app
- But now includes the relationships between adjacent levels

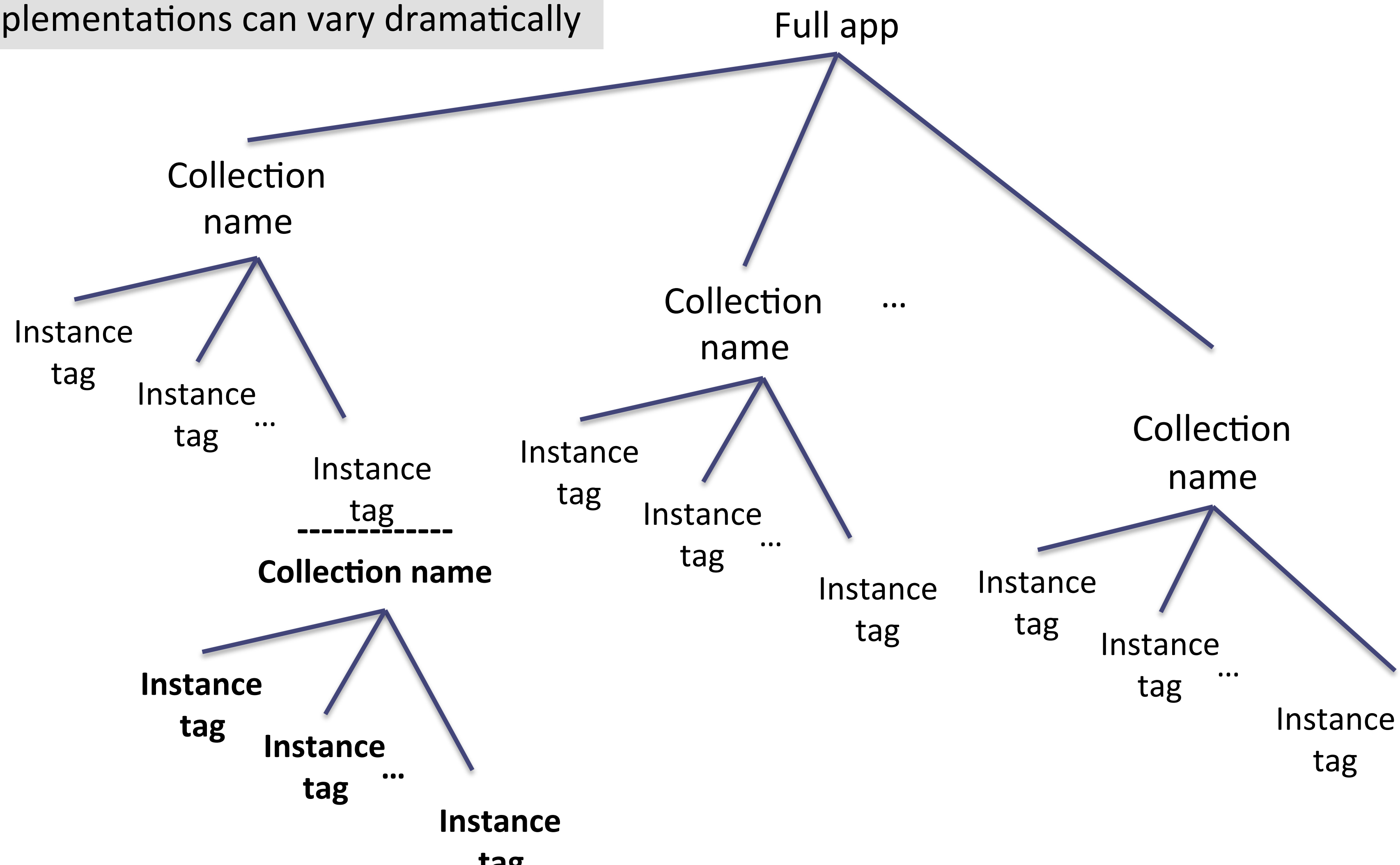
Current fixed 3 level hierarchy

This is at a high level
Implementations can vary dramatically



General hierarchy looks like flat CnC at every level

This is at a high level
Implementations can vary dramatically



Types of hierarchical relationships

SIMD: Single instruction / multiple data
Usually means "in parallel".
Here it says nothing about parallelism.

4 possibilities

- Applied to:
  Computation / data
- Types of decomposition:
  Heterogeneous / homogeneous

Like an array

Like SIMD

	Data	Computation
Homogeneous	[x: j, k] = [x: j', k'] Special case: [x: j] = [x: j, k]	(foo: j, k) = (foo: j', k') Special case: (foo: j) = (foo: j, k)

Types of hierarchical relationships

4 possibilities

- Applied to:

  Computation / data

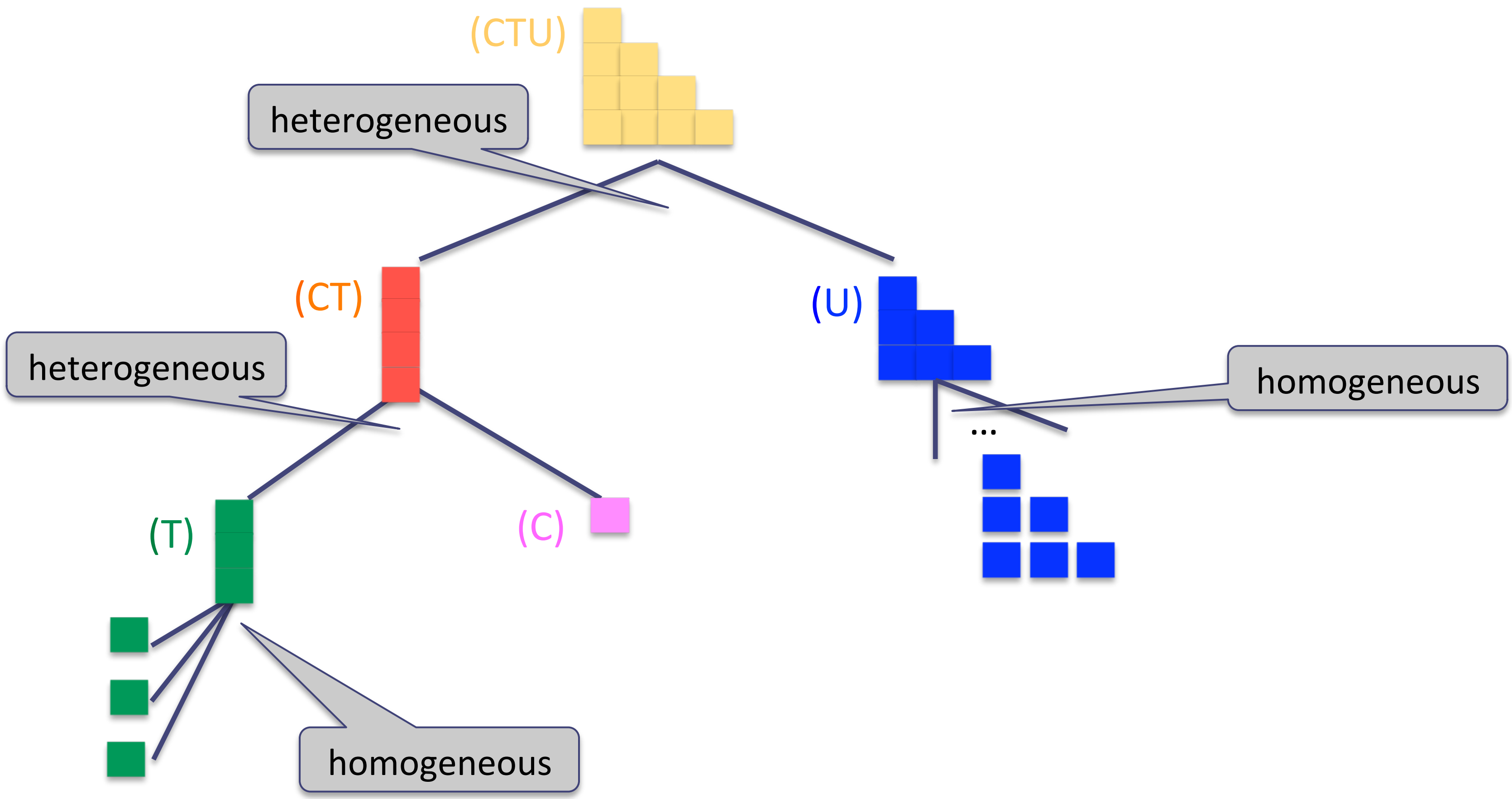
- Types of decomposition:

  Heterogeneous / homogeneous

MIMD: Multiple instruction / multiple data
Usually means "in parallel".
Here it says nothing about parallelism.

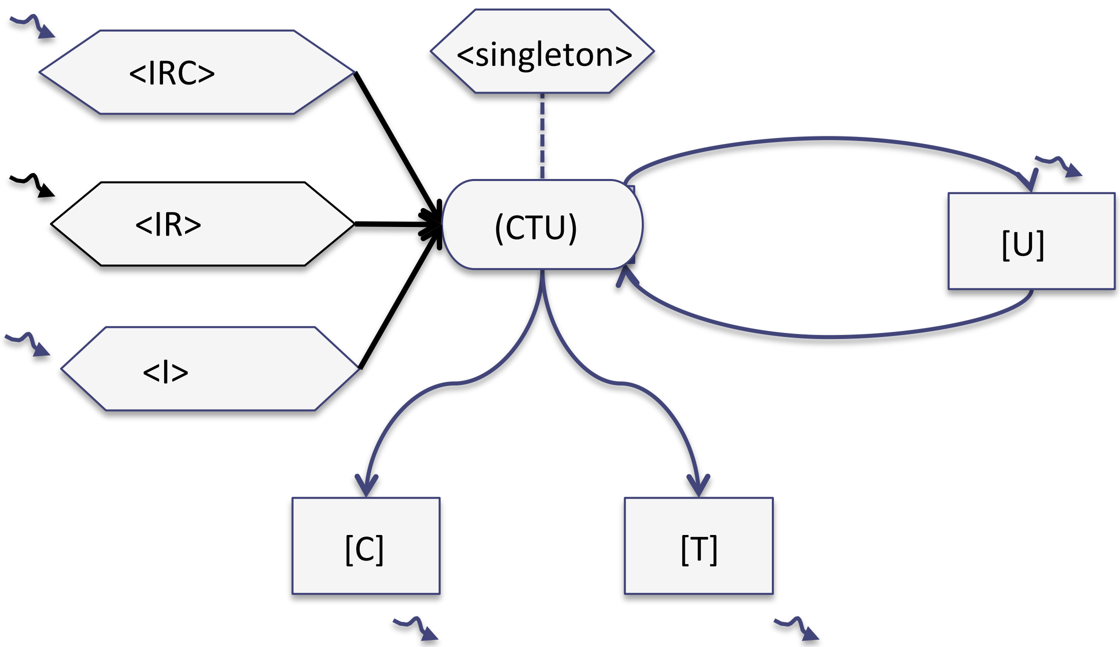
	Data	Computation
Homogeneous	[x: j, k] = [x: j', k'] (Like an array) Special case: [x: j] = [x: j, k]	(foo: j, k) = (foo: j', k') (Like SIMD) Special case: (foo: j) = (foo: j, k)
Heterogeneous	[x: j] = [y: j], [z: j] (Like a struct)	(foo: j) = {graph: j} (Like MIMD)

Decompositions



distinct collections
Same color = same name = same collection

Cholesky CnC graph spec



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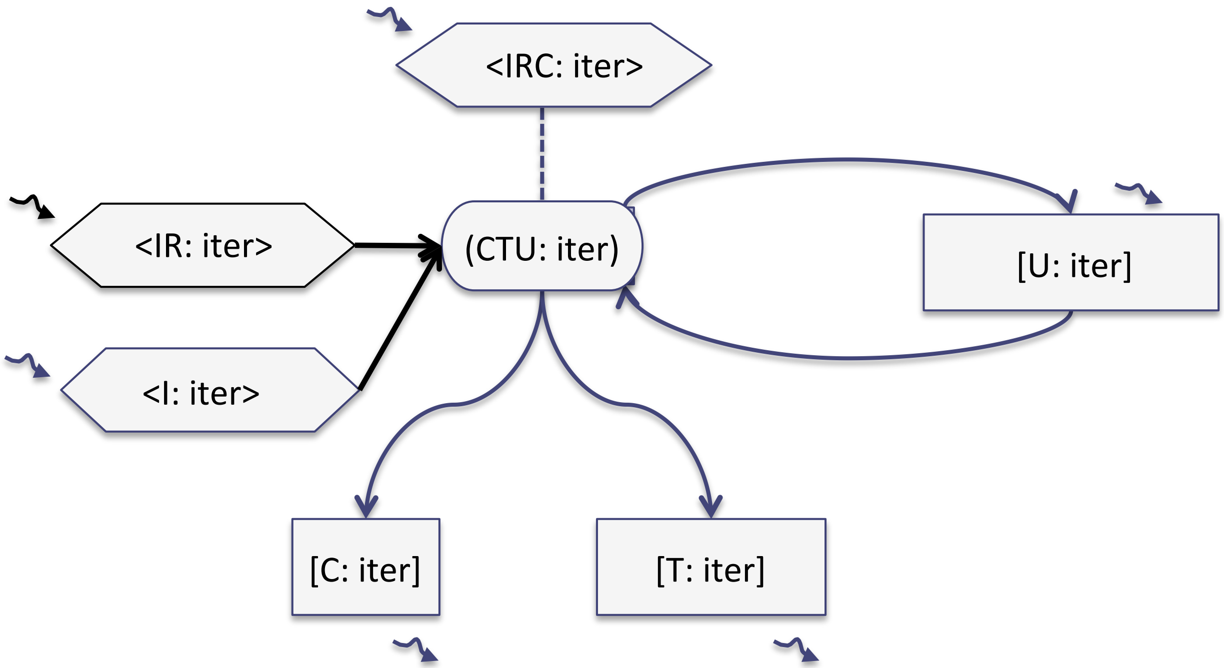
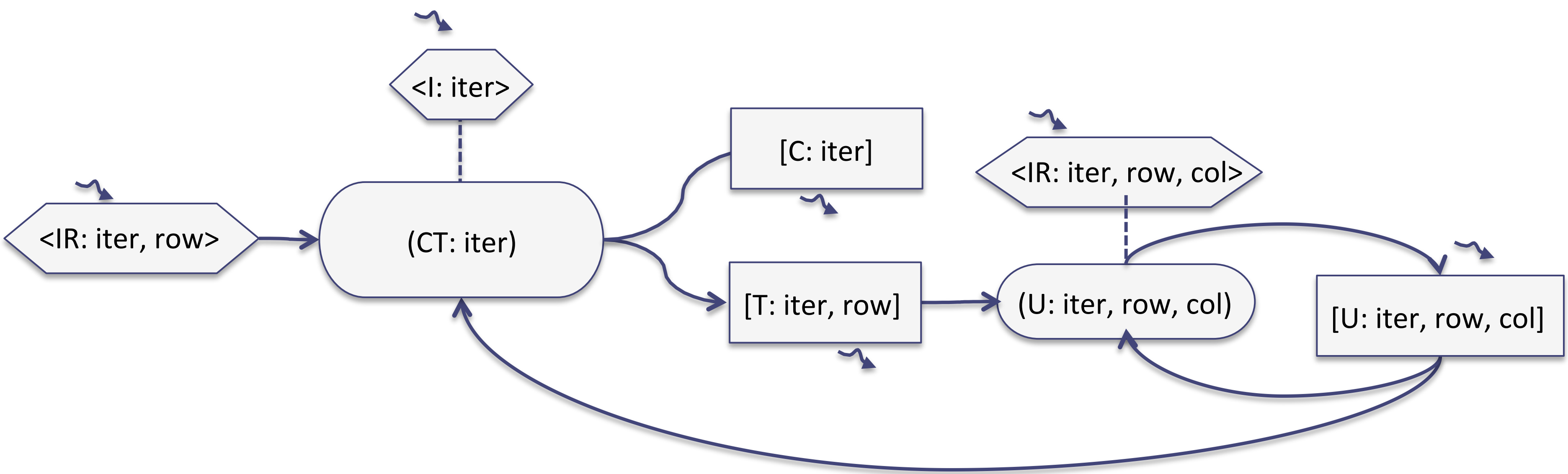


This is a homogeneous decomposition of (CTU) into children (CTU:iter). These children all look the same for different values of iter

Cholesky CnC graph spec



This is a further (heterogeneous) decomposition of (CTU: iter)
Into 2 distinct computation steps (CT: iter) and (U: iter, row, col)

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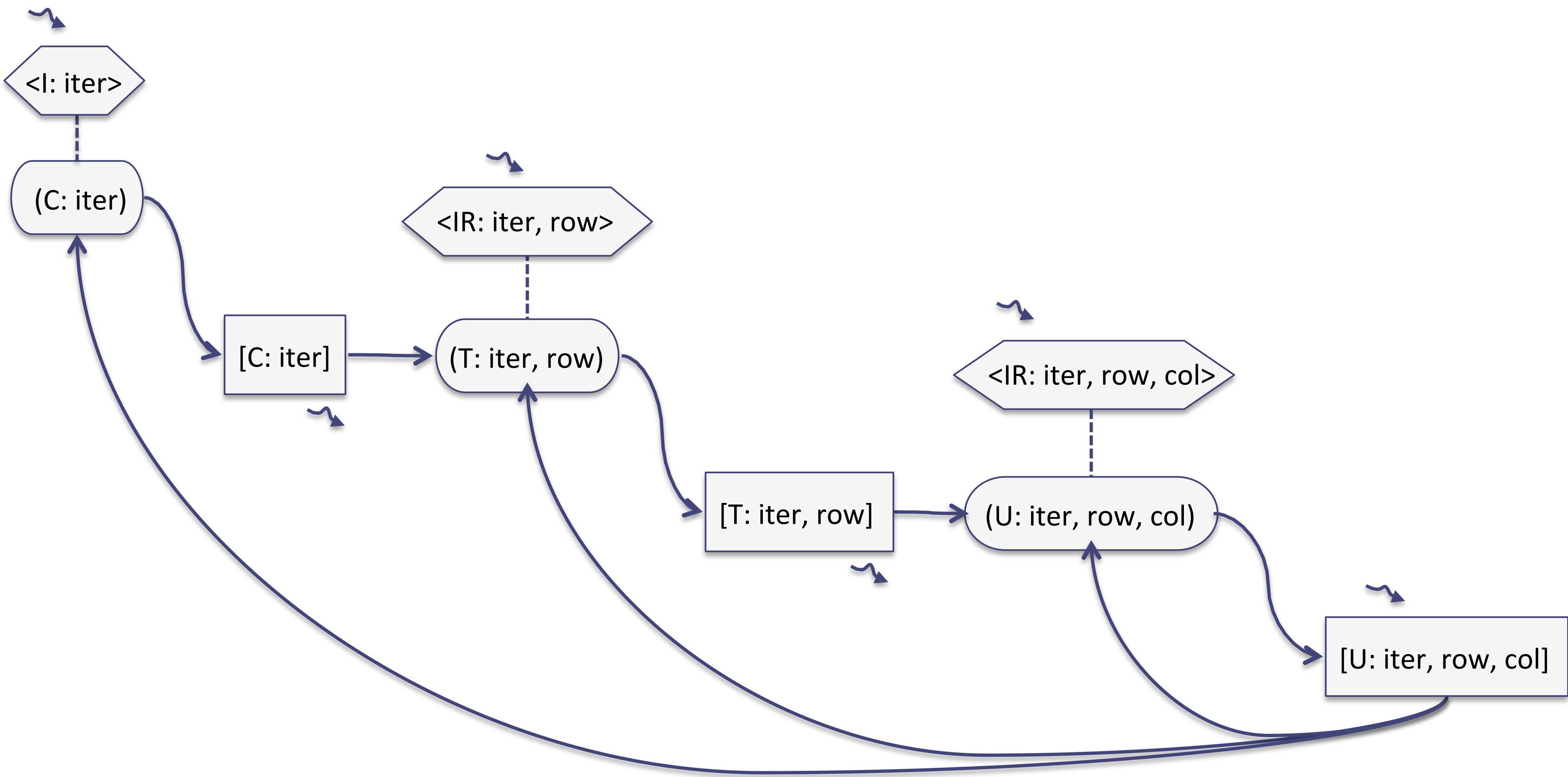
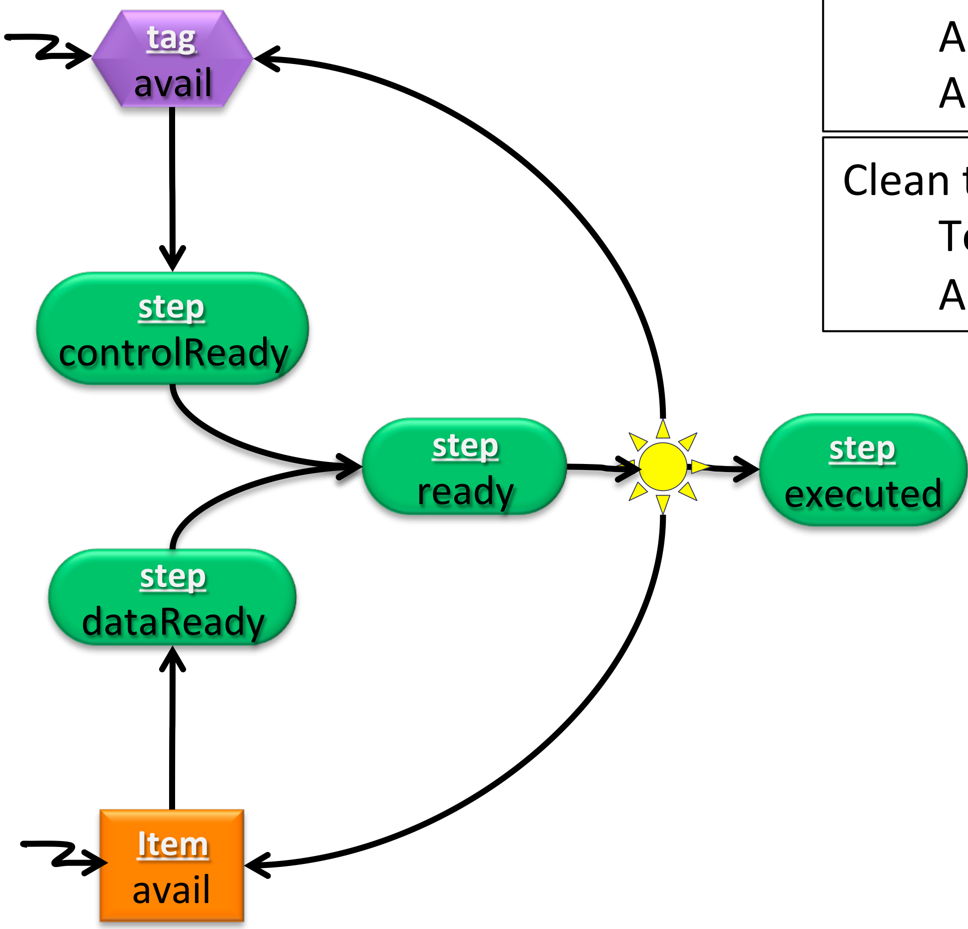


This is a further (heterogeneous) decomposition of (CT: iter)
Into 2 distinct computation steps (C: iter) and (T: iter, row)

Semantics of flat CnC:



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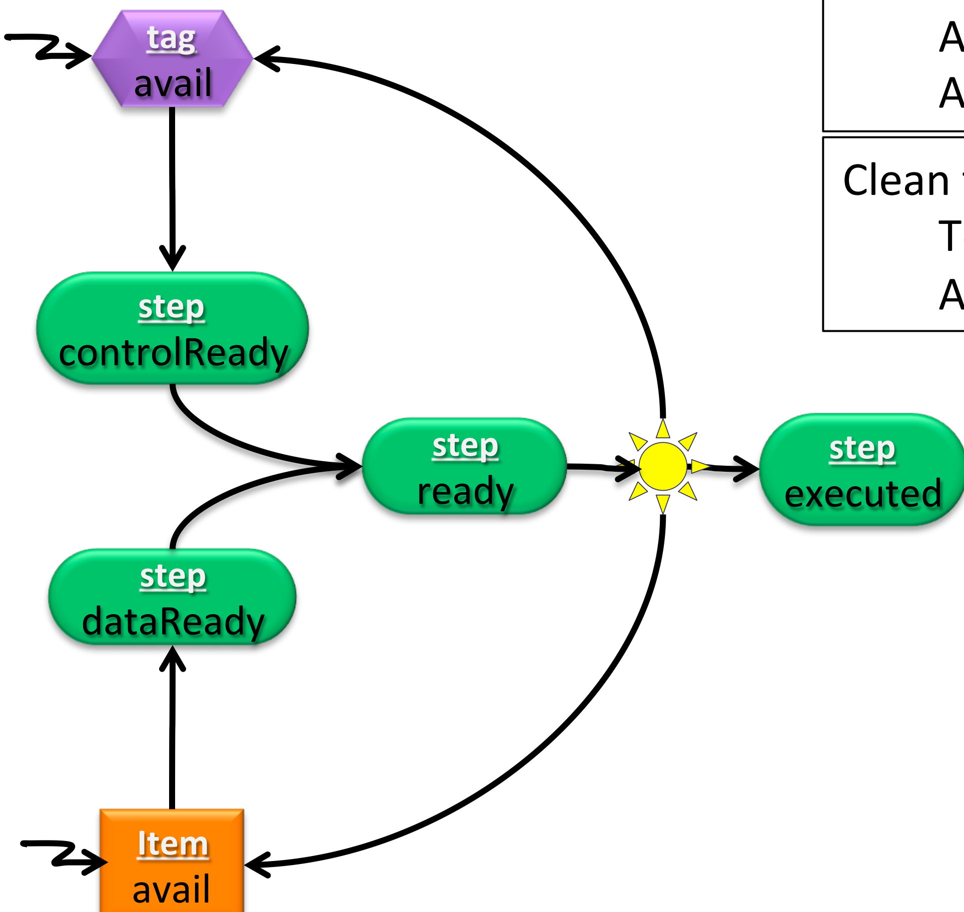

Lower level graph

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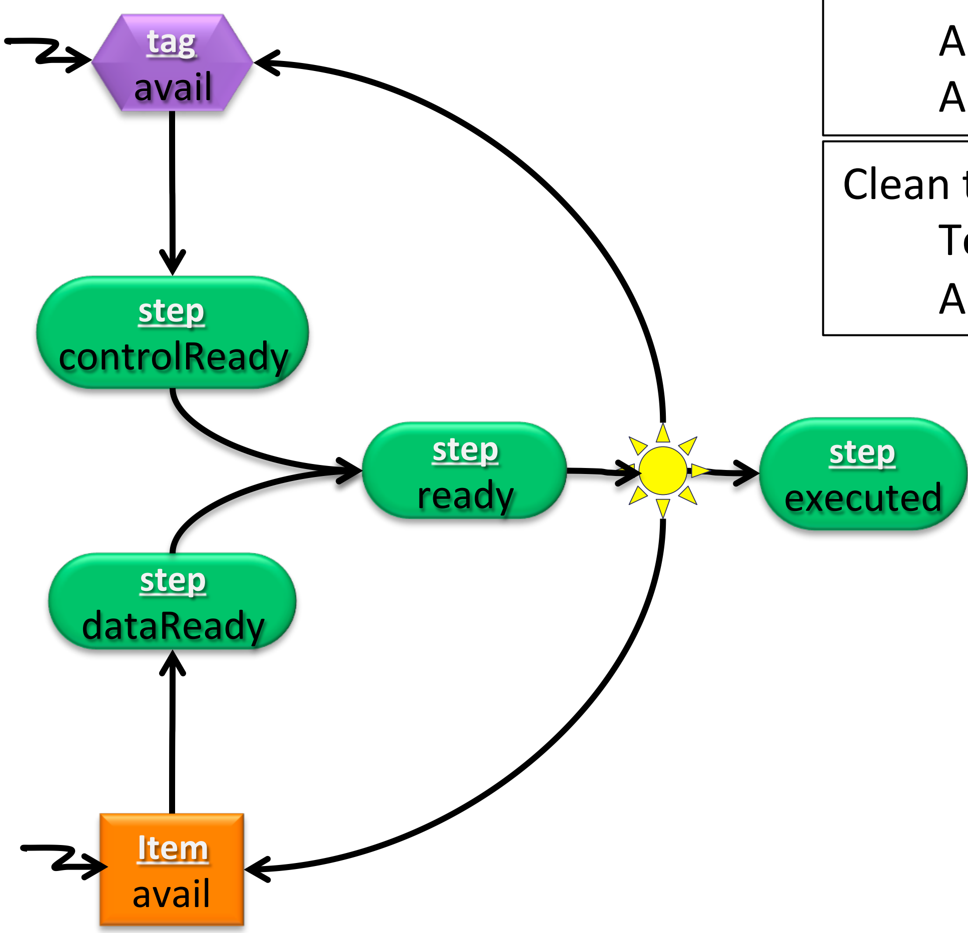

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terminated

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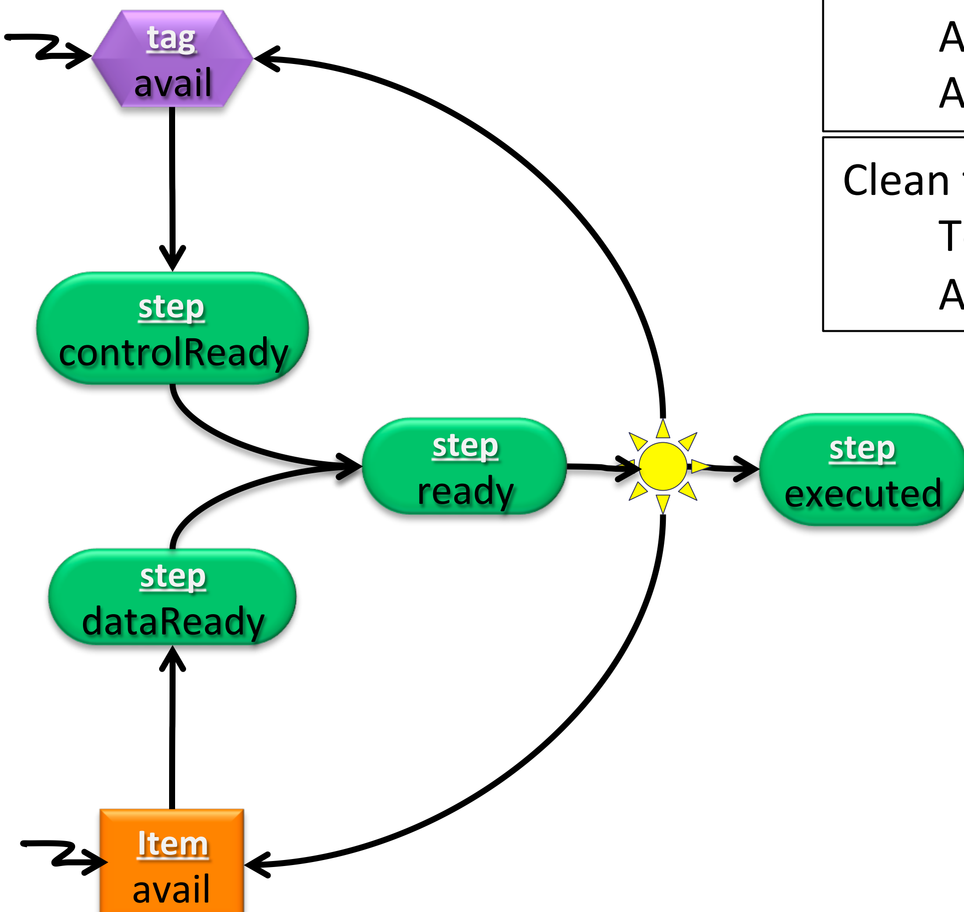

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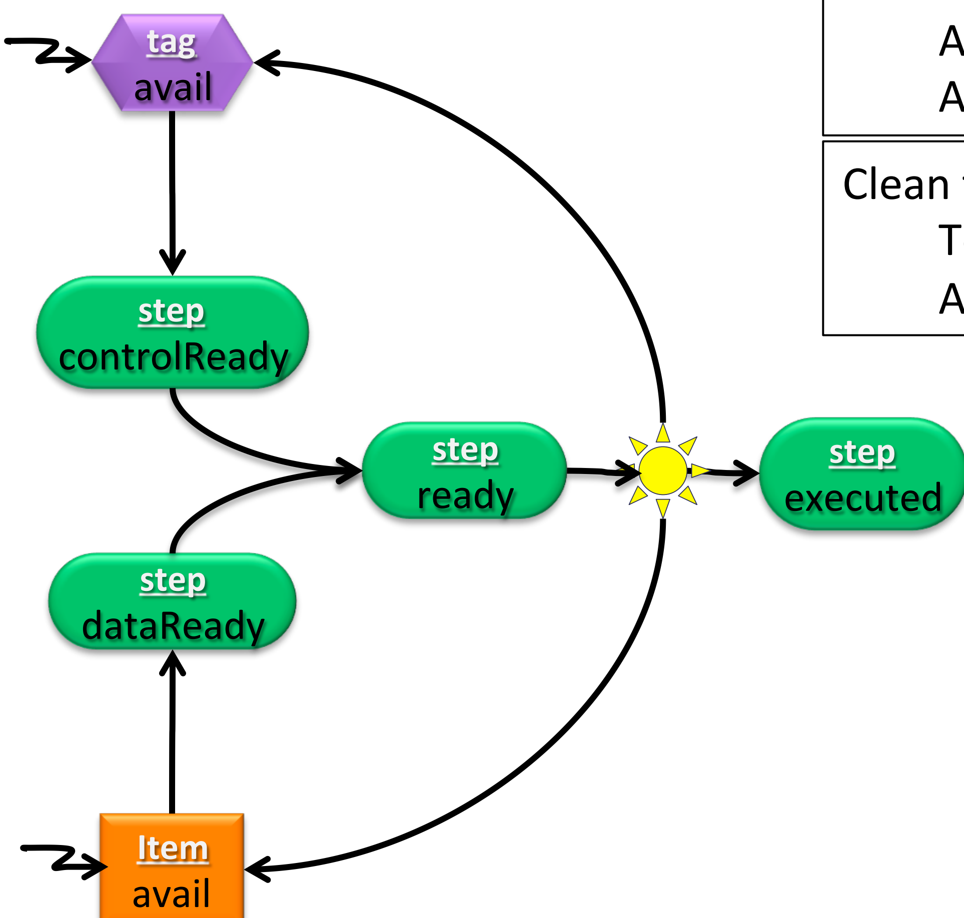

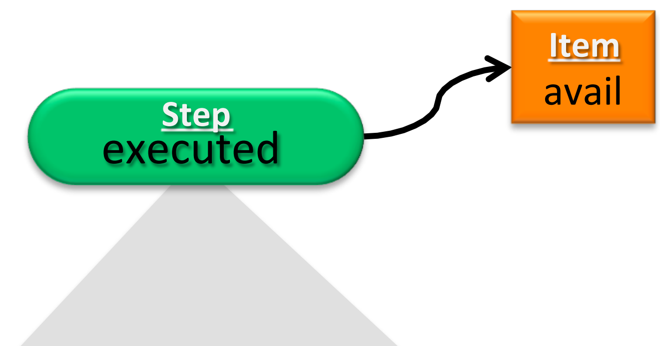

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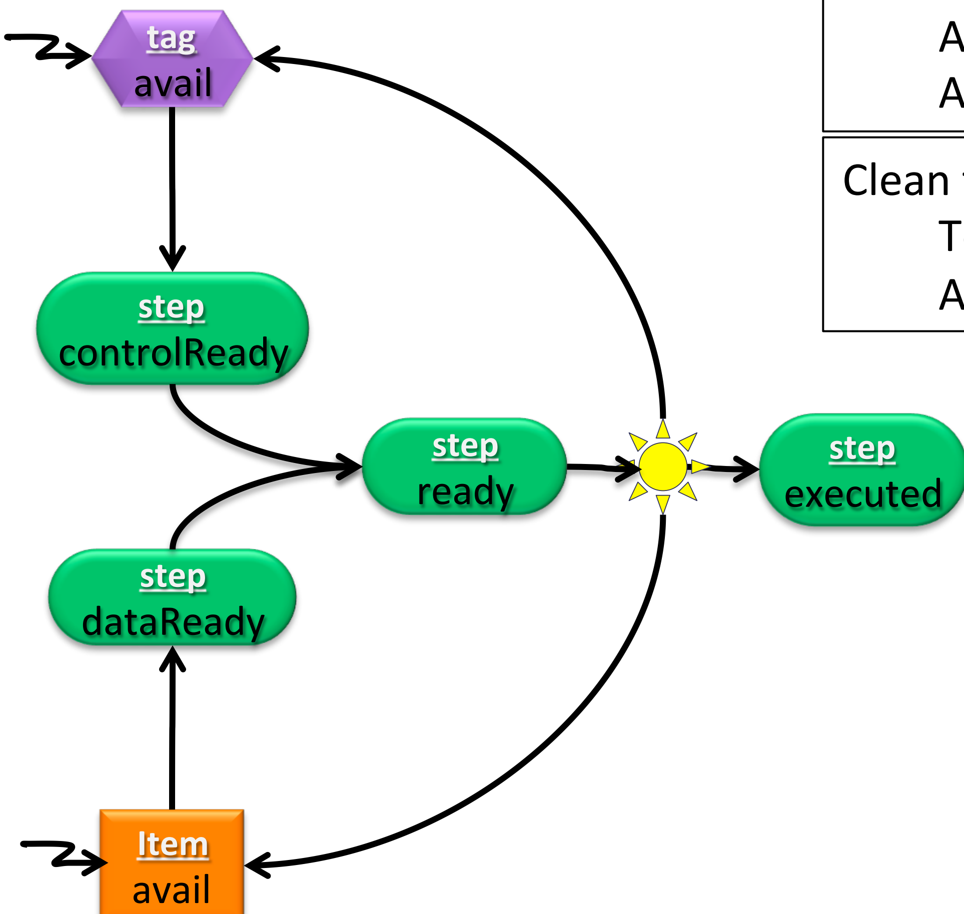

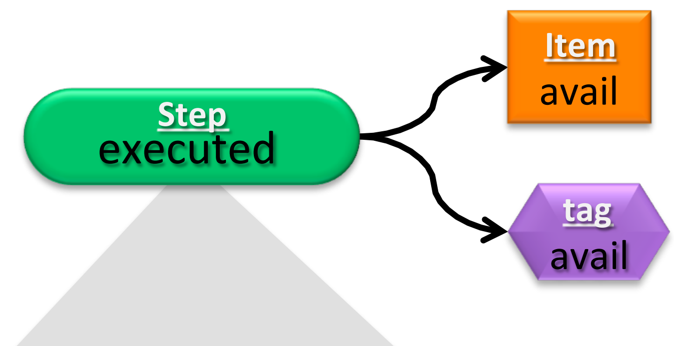

Lower level graph
terminated

Hierarchical nodes that are not step-like

Like a sub-graph of a larger graph or like an app

- Doesn't need to live by the in/compute/out rule
  - Most of our current apps are step-like
- The Intel system supports non-step like nodes as subgraphs of a larger graph
  - Examples reductions, joins

Reuse

- We want to reuse hierarchical nodes
  - Multiple times within the same app or from libraries
  - Step-like or graph-like
  - Either case innards can be public or private
- If public
  - As if it were built for the app itself
  - Can analyze and optimized wrt its position
- If private
  - It's a black box
  - Can optimize it as a whole (move or delete)

Constraints and optimizations

Constraints on hierarchy

- Every level of a hierarchical CnC spec is a legal CnC spec:
  - Steps at every level must be step-like:
    - Can get all their input, compute, put their output and terminate
  - Data items at every level must item-like
    - Are dynamic single-assignment
- The meaning of the parent node is identical to the meaning of the children taken as a whole
- Implication:
  - Parent/child relationship of steps and the parent/child relationship of items must be consistently determined

One example of an optimization: Interchange

Computations

- 4 parent/child combinations
  - SIMD of SIMD
  - MIMD of MIMD
  - SIMD of MIMD
  - MIMD of SIMD

Interchange is legal

if the result is step-like at both levels

Data

- 4 parent/child combinations
  - Struct of structs
  - Struct of arrays
  - Array of structs
  - Array of arrays

Interchange is legal

if the result DSA at both levels

Conclusions

- Hierarchy is useful for the domain expert and for the tuning expert
- Hierarchy is not only for computation but also hierarchical
  – Discussed: Static & dynamic analysis, static & dynamic tuning, etc.
  – But also: Documentation, development, testing, debugging, checkpoint-continue,

End

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