RDF Data Pipelines for Semantic Data Federation

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Please download the latest version of these slides:

http://dbooth.org/2011/pipeline/

Who am I?

- **David Booth, PhD:**
  - **Software architect**
  - **Cleveland Clinic 2009-2010**
  - **HP Software & other companies prior**
  - **Focus on semantic web architecture and technology**

- **Christopher Pierce, PhD:**
  - **Manager of Informatics, Cleveland Clinic**
  - **Pioneered use of RDF for patient data**
  - **W3C case study:**
    http://www.w3.org/2001/sw/sweo/public/UseCases/ClevelandClinic/

What is this about?

- **Vision for multi-stage <u>data production pipelines</u>**
  - **Dependency networks of nodes that process/store data**
  - **Intended for semantic data federation or integration**
- **Light weight, decentralized, very loosely coupled**
  - **Point-to-point communication**
- **Designed for RDF data, but data agnostic**
- **Based on:**
  - **RDF pipeline descriptions**
  - **HTTP dependency graphs**
  - **SPARQL**
- **Cache oriented**
- **Updates only what <u>needs</u> to be updated**

Related work

- Sparql Motion, from Top Quadrant
  - A “visual scripting language for semantic data processing”
  - http://www.topquadrant.com/products/SPARQLMotion.html
  - Similarities: Easy to visualize; Easy to build a pipeline
  - Differences: Central control & execution; Not cache oriented
- DERI Pipes
  - A “paradigm to build RDF-based mashups”
  - http://pipes.deri.org/
  - Similarities: Very similar goals
  - Differences: XML pipeline definition; Central control; Not cache oriented
- NetKernel
  - An “implementation of the resource oriented computing (ROC)” – think REST
  - http://www.1060research.com/netkernel/
  - Similarities: Based on REST (REpresentation State Transfer)
  - Differences: Lower level; Expressed through programming language bindings (Java, Python, etc.) instead of RDF
- Propagators, by Gerald Jay Sussman and Alexey Radul
  - Scheme-based programming language for propagating data through a network
  - http://groups.csail.mit.edu/mac/users/gjs/propagators/revised-html.html
  - Similarities: Auto-propagation of data through a network
  - Differences: Programming language; Finer grained; Uses partial evaluation; Much larger paradigm shift
- Enterprise Service Bus (ESB)
  - http://soa.sys-con.com/node/48035#
  - Similarities: Similar problem space
  - Differences: Central messaging bus and orchestration; Heavier weight; SOA, WS*, XML oriented; Different cultural background
- Extract, Transform, Load (ETL)
  - http://www.pentaho.com/
  - Similarities: Also used for data integration
  - Differences: Central orchestration and storage; Oriented toward lower level format transformations

What this is <u>not</u>

- **Not a universal data model approach**
  - **No automatic data model/format translation**
- **Not a centralized approach**
  - **No central server or controller**
    - **Each node acts independently**
  - **But all nodes share the same RDF pipeline <u>definition</u>**
- **Not a workflow language**
  - **No flow-of-control operators**
  - **Focus is on data production pipelines**

Where did this come from?

- **Ideas originated while at HP Software**
- **Motivated by the need to <u>manage RDF data production in a scalable way</u>**
- **Ideas further extended from Cleveland Clinic work**
  - **Large amounts of patient data, lab data, etc. to be integrated and transformed**

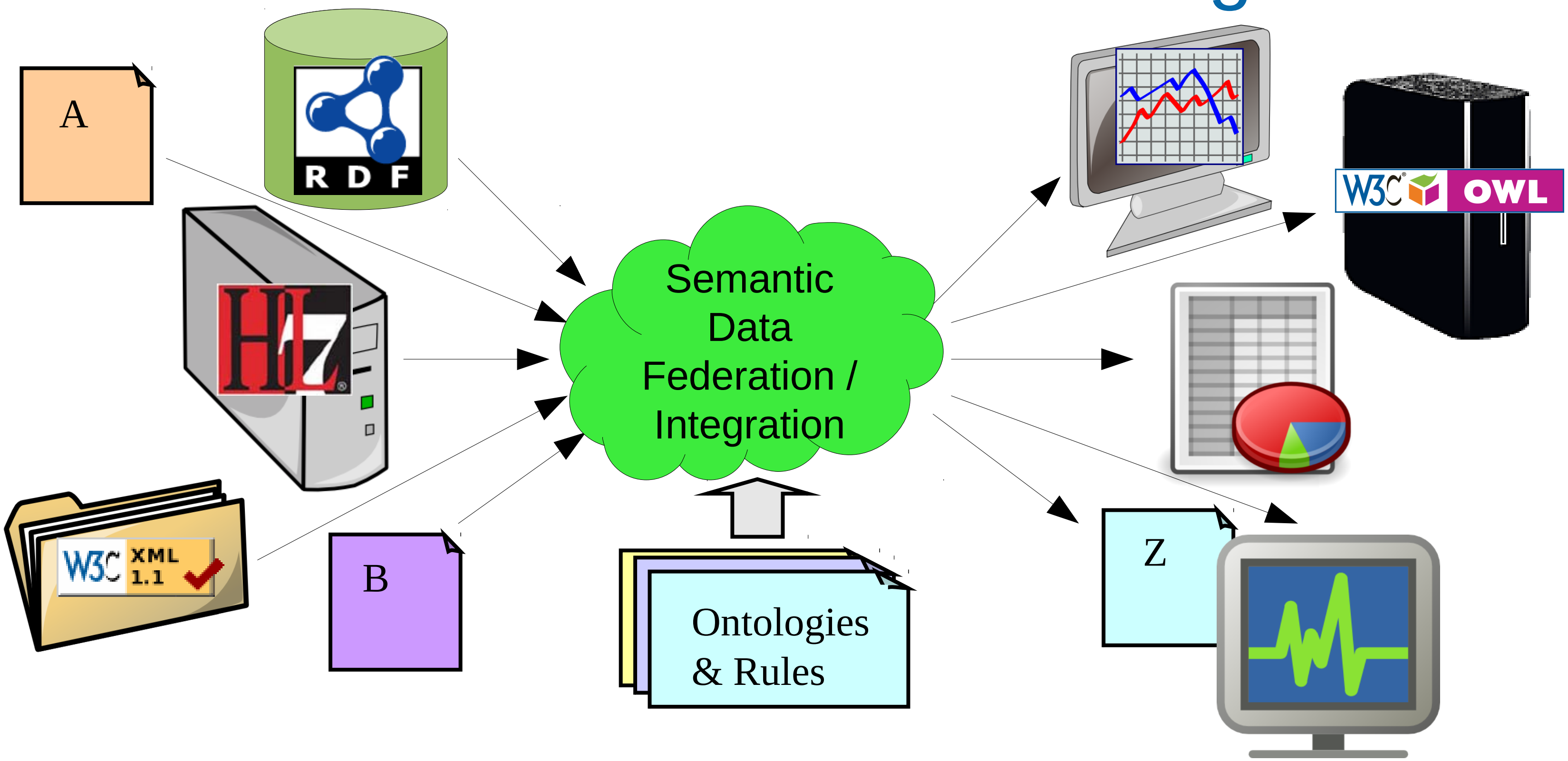
Why?

- **Flexible:**
  - **Any kind of data – not only RDF**
  - **Any kind of custom code (using wrappers)**
  - **Internal homogeneous pipelines**
  - **Distributed heterogeneous pipelines**
- **Efficient**
  - **Updates only what <u>needs</u> to be updated**
  - **Communicates with native protocols when possible, HTTP otherwise**
- **Easy:**
  - **Easy to implement nodes (using standard wrappers)**
  - **Easy to define pipelines (using a few lines of RDF)**
  - **Easy to visualize**
  - **Easy to maintain – very loosely coupled**

Caveat

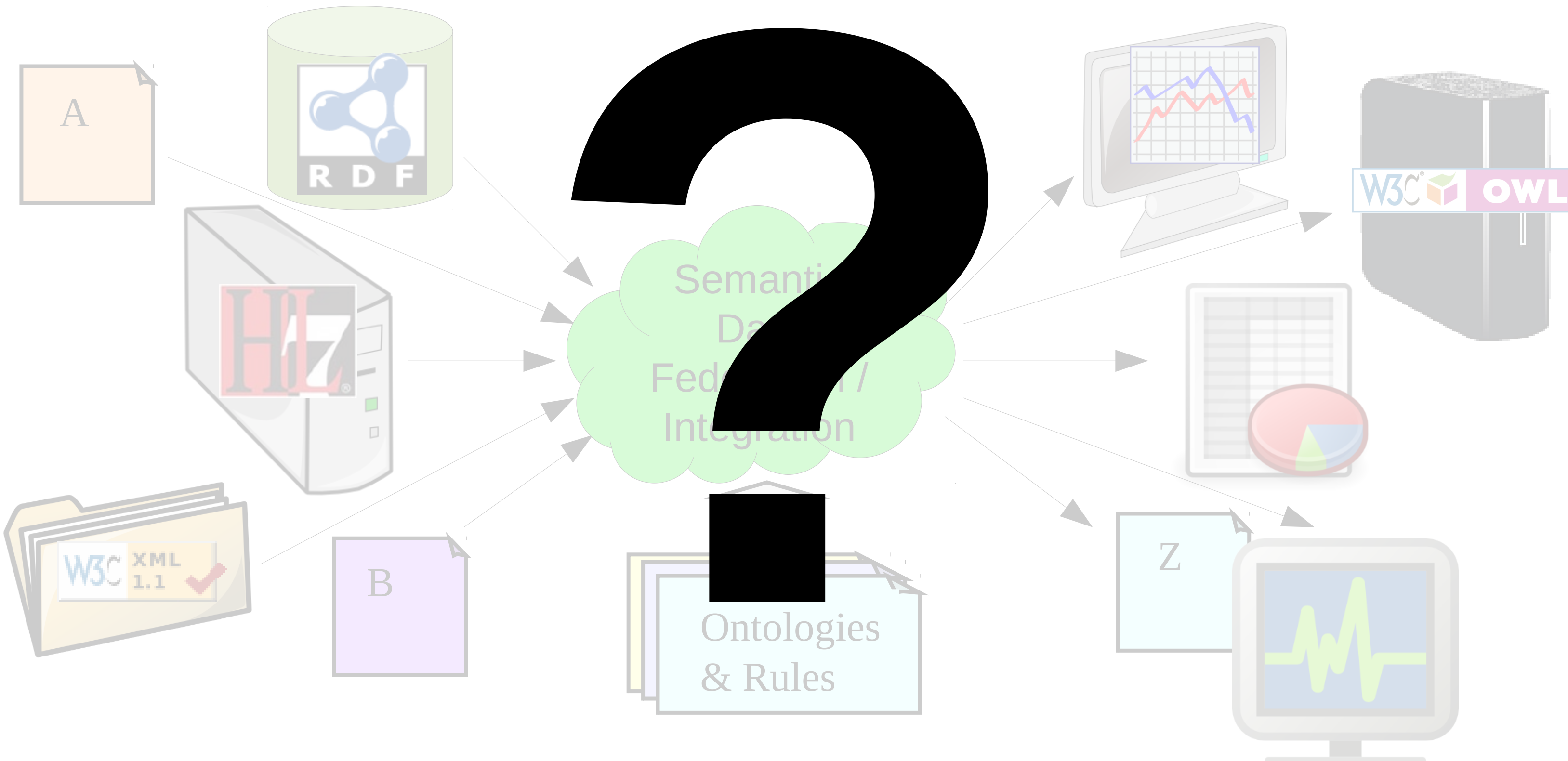
- **This is an architectural approach – not a product**
- ***Interested in your feedback!***

Semantic data federation / integration



- Many data sources and applications
- Many technologies and protocols
- Goal: Each application wants the illusion of a single, unified data source
- Strategy:
  - Use ontologies and rules for semantic transformations
  - Convert to/from RDF at the edges; Use RDF in the middle

How?



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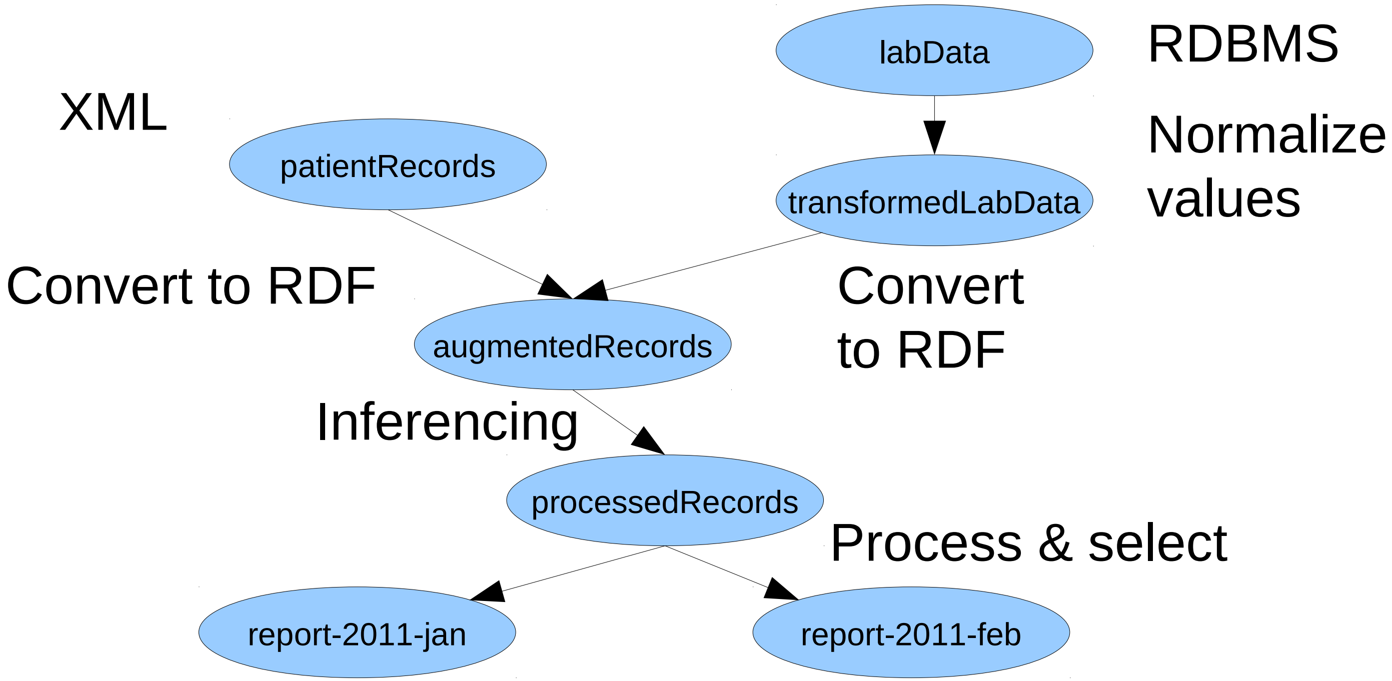
Example: Monthly report pipeline

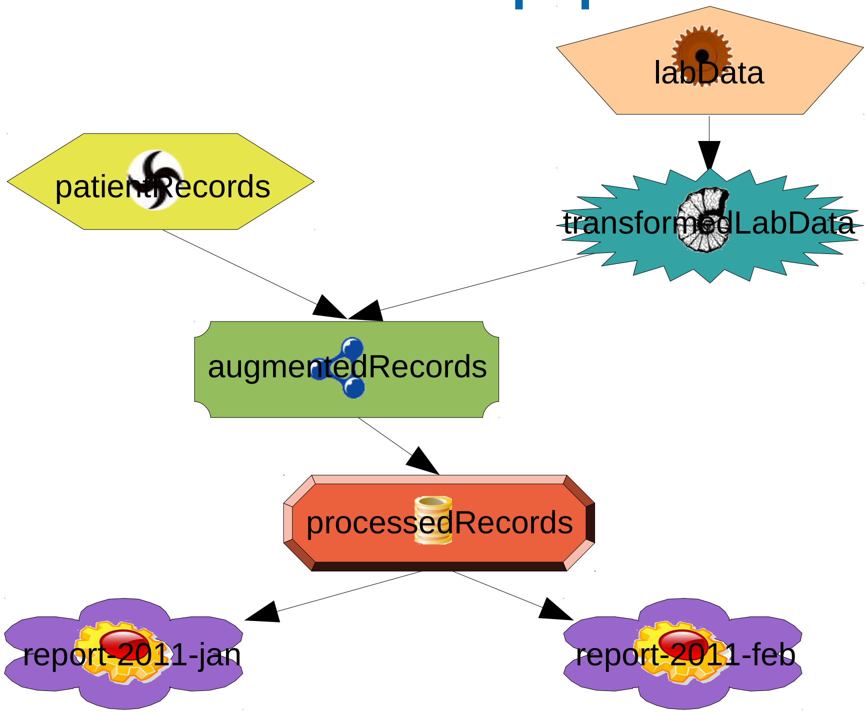


- **Pipeline of multiple data sources and data production stages**
  - **A directed graph of nodes**
  - **Each node is one stage: processing and/or data storage**

How?

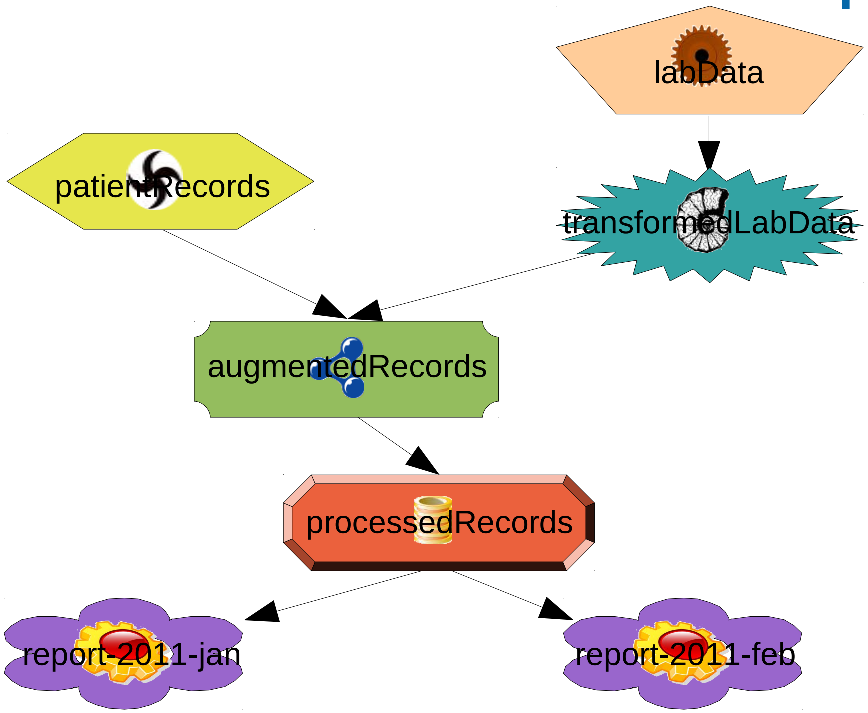
- Pipeline of multiple data sources and data production stages
  - A directed graph of nodes
  - Each node is one stage: processing and/or data storage

Ad hoc data pipeline



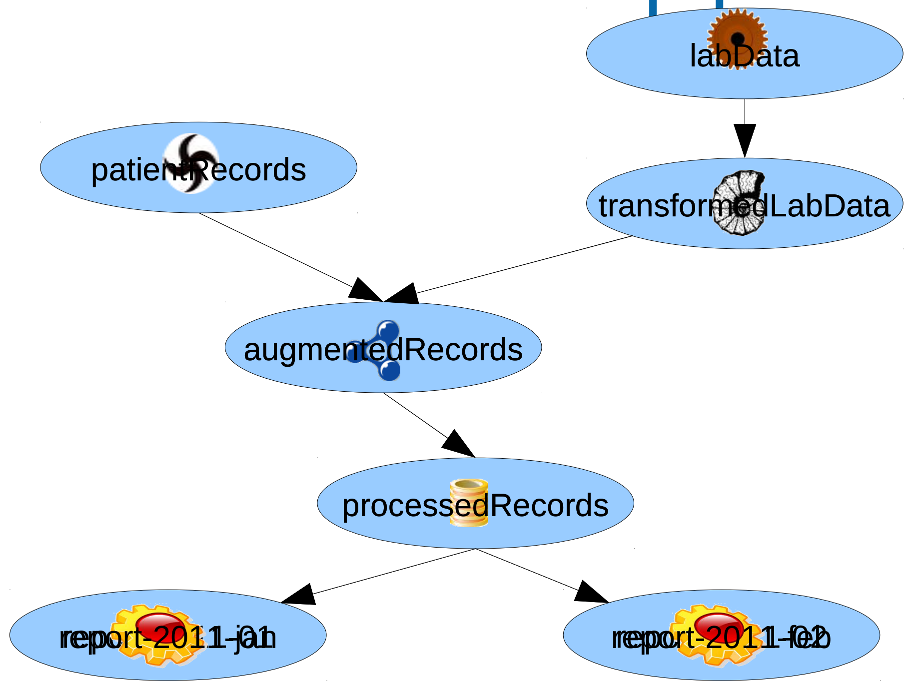
- **Typically involves:**
  - **Mix of technologies: shell scripts, SPARQL, databases, web services, etc.**
  - **Mix of formats – RDF, relational, XML, etc.**
  - **Mix of interfaces: Files, WS, HTTP, RDBMS, etc.**

Pros and cons of ad hoc data pipeline



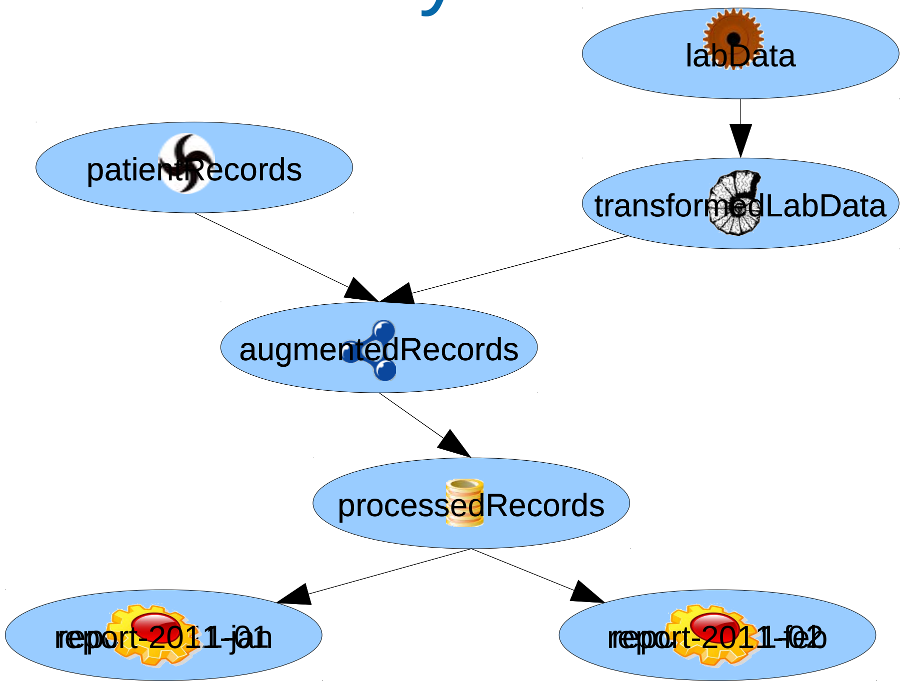
- **Pros: Low initial risk; Can be built incrementally from existing pieces**
- **Cons: High long term cost; Fragile; Difficult to understand & maintain**

Vision: RDF data pipeline



- **Pipeline defined in RDF**
  - **An <u>HTTP dependency graph</u>**
- **Uses a <u>uniform interface:</u> RESTful HTTP**
- **Uses <u>wrappers</u> to handle:**
  - **Inter-node communication**
  - **Node update invocation**

Flexibility retained

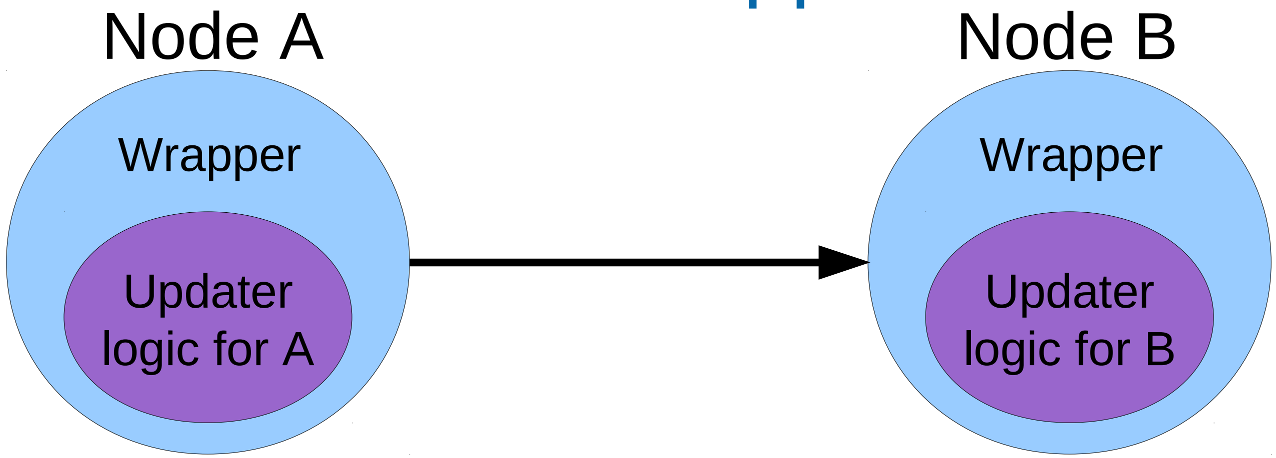


- **Still permits:**
  - **Any technology <u>inside</u> nodes: shell scripts, SPARQL, databases, web services, etc.**
  - **Any data <u>format</u> between nodes – RDF or other**

Example pipeline definition (in N3)

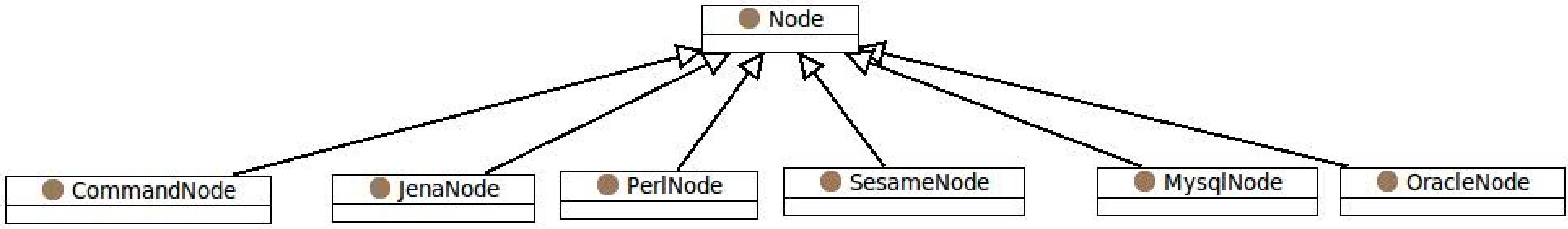
```
@prefix p: <http://purl.org/pipeline/ont#> .
@prefix : <http://localhost/> .
:patientRecords a p:Node .
:labData a p:Node .
:transformedLabData a p:Node ;
        p:inputs ( :labData ) .
:augmentedRecords a p:Node ;
        p:inputs ( :patientRecords :transformedLabData ) .
:processedRecords a p:Node ;
        p:inputs ( :augmentedRecords ) .
:report-2011-jan a p:Node ;
        p:inputs ( :processedRecords ) .
:report-2011-feb a p:Node ;
        p:inputs ( :processedRecords ) .
```

Node wrappers



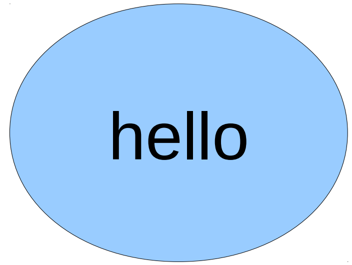
- **Nodes may be implemented in arbitrary ways**
  - **Command script, SPARQL rules, HTTP web service, Relational database, etc.**
- **Custom node logic (“updater”) is hidden in wrapper**
  - **Wrappers provided for common node types**
- **Wrappers handle:**
  - **Inter-node communication (HTTP and potentially other protocols)**
  - **Node invocation**

Example node wrapper types



- **CommandNode is the default Node type**

Example one-node pipeline definition: “hello world”




```
1.  @prefix p: <http://purl.org/pipeline/ont#> .
2.  @prefix : <http://localhost/> .
3.  :hello a Node ;
4.        p:updater "hello-updater" .
```

Output can be retrieved from <u>http://localhost/hello</u>

Implementation of “hello world” Node

Code in hello-updater:

```
#!/bin/bash -p
echo Hello from $1 on `date`
```

- **hello-updater is then placed where the wrapper can find it**
  - **E.g., Apache WWW directory**

Invoking the “hello world” Node

When URL is accessed:

```
http://localhost/hello
```

Wrapper invokes the updater as:

```
hello-updater http://localhost/hello > /.../hello-stdout.txt
```

Wrapper serves /.../hello-stdout.txt content:

```
Hello from http://localhost/hello on Wed Apr 13 14:54:57 EDT
2011
```

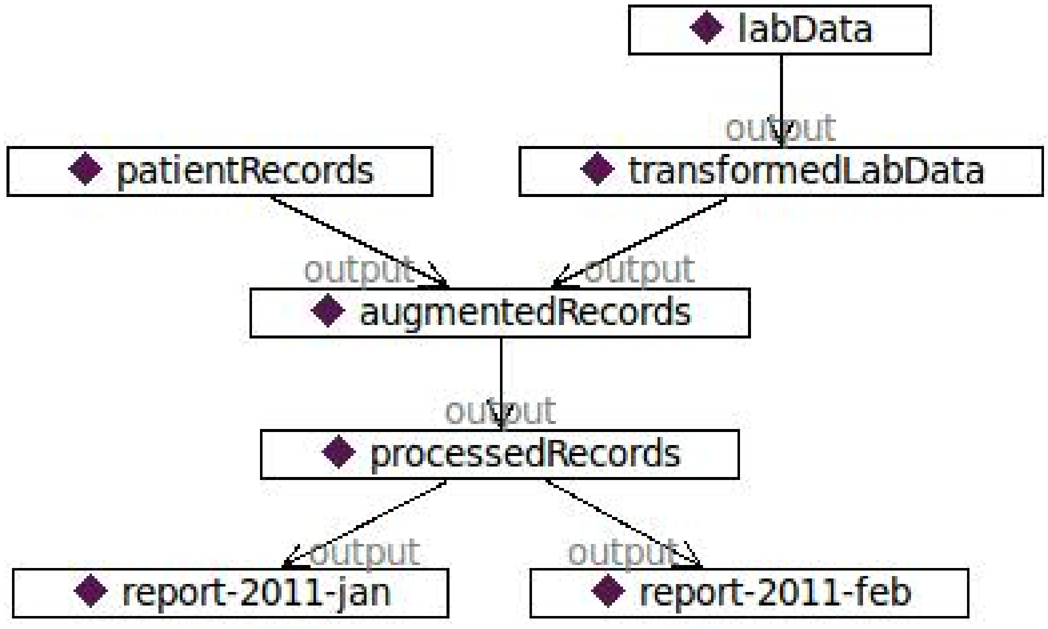
Why RDF pipeline definition?

- **Directed graphs are natural to RDF**
- **Permits inferencing**
- **Easy visualization . . .**

Visualizing ad hoc pipelines

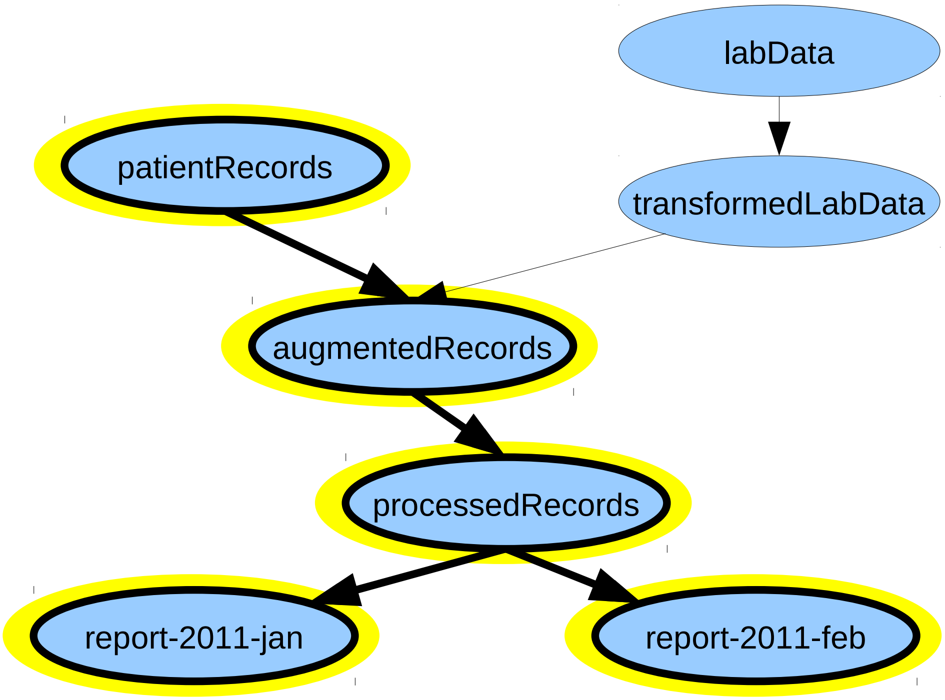
- **Ad hoc pipelines are difficult to figure out**
  - **Definition is spread around in source files**
  - **Big picture is obscured**
- **Difficult to visualize**

Automatic pipeline visualization



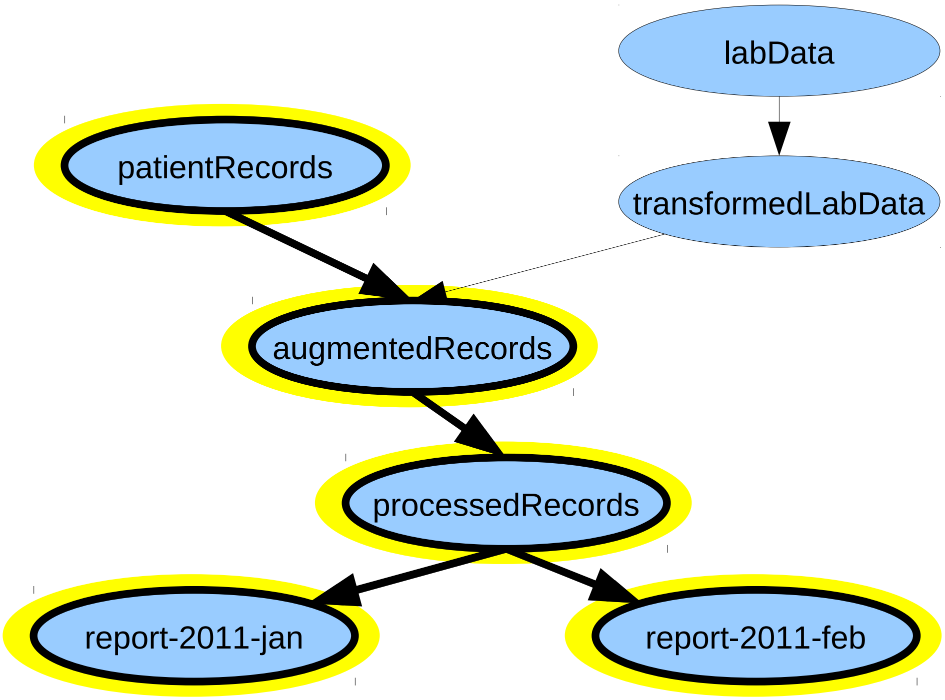
- **RDF pipeline definition permits visualization to be <u>auto-generated</u>**
- **Self-documenting**

Why a dependency graph?



- **Wrappers can:**
  - **Keep track of node dependencies**
  - **Invoke a node automatically <u>as needed</u>**
- ***Think Ant or Make***

Why cache oriented?



- **Node is updated <u>only</u> if one of its inputs changed**
  - **Otherwise cached output is used**

What do I mean by “cache”?

- ~~**Meaning 1: A local copy of some other data store**~~
  - ~~**I.e., the same data is stored in both places**~~

- **Meaning 2: Stored data that is regenerated when stale**
  - **Think: caching the results of a CGI program**
  - **Results can be served from the cache if inputs have not changed**

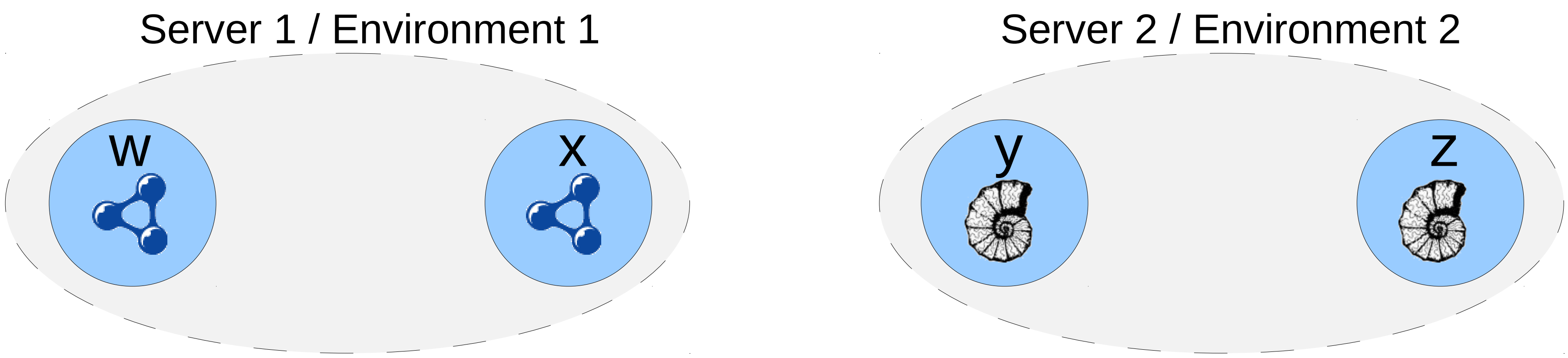
Why a uniform interface?

Simplifies implementation

Same interface for both:

- **Internal / homogeneous pipelines**
- **Distributed / heterogeneous pipelines . . .**

Internal / homogeneous versus distributed / heterogeneous pipeline

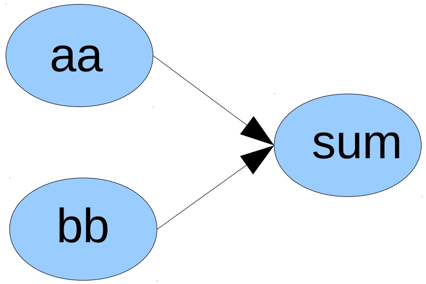


- **Internal / homogeneous:**
  - **Same server**
  - **Same processing environment**
  - **E.g. named graphs within the same Java RDF store**
- **Distributed / heterogeneous:**
  - **Different server**
  - **Different processing environment**
  - **E.g., Java RDF store on one server to relational database on another**

Why HTTP?

- **Simple, ubiquitous protocol**
- **Allows any data format (RDF or other)**
- **Built-in cache support: Last-Modified, ETag, etc.**
- **Easy testing**

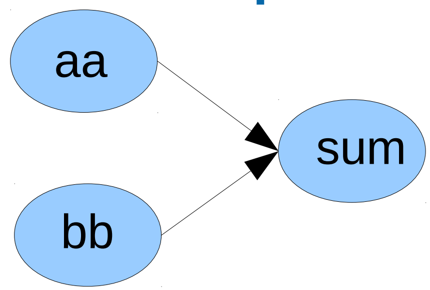
Example pipeline: sum two numbers



Pipeline definition:

```
1.@prefix p: <http://purl.org/pipeline/ont.n3#> .
2.@prefix : <http://localhost/> .
3.:aa a p:Node .
4.:bb a p:Node .
5.:sum a p:Node ;
6.         p:inputs ( :aa :bb ) ;
7.         p:updater "sum-updater" .
```

sum-updater implementation



Node implementation (in Perl):

```
1.#! /usr/bin/perl -w
2.# Add numbers from two nodes.
3.my $sum = `cat $ARGV[1]` + `cat $ARGV[2]`;
4.print "$sum\n";
```

aa cache (pointing to `$ARGV[1]`)

bb cache (pointing to `$ARGV[2]`)

Why SPARQL?

- **Standard RDF query language**
- **Can help bridge RDF <--> relational data**
  - **Relational --> RDF: mappers are available**
    http://www.w3.org/wiki/Rdb2RdfXG/StateOfTheArt
  - **RDF --> relational: SELECT returns a table**
- ***Also* can act as a rules language**
  - **CONSTRUCT or INSERT**

SPARQL CONSTRUCT as an inference rule

- **CONSTRUCT creates (and returns) new triples if a condition is met**
  - **That's what an inference rule does!**
- **CONSTRUCT is the basis for SPIN (Sparql Inference Notation), from TopQuadrant**
- **However, in standard SPARQL, CONSTRUCT only *returns* triples (to the client)**
  - **Returned triples must be inserted back into the server – an extra client/server round trip**

SPARQL INSERT as an inference rule

- **INSERT creates and asserts new triples if a condition is met**
  - **That's what an inference rule does!**
- **Single operation – no need for extra client/server round trip**

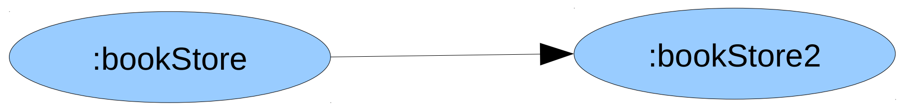
- **Issue: How to apply inference rules repeatedly until no new facts are asserted?**
  - **E.g. transitive closure**
  - **cwm --think option**
  - **SPIN**
- **In standard SPARQL, requested operation is only performed <u>once</u>**
- ***Would be nice to have a SPARQL option to REPEAT until no new triples are asserted***

SPARQL bookStore2 INSERT example

```
# Example from W3C SPARQL Update 1.1 specification
#
PREFIX dc:  <http://purl.org/dc/elements/1.1/>
PREFIX xsd: <http://www.w3.org/2001/XMLSchema#>

INSERT
  { GRAPH <http://example/bookStore2> { ?book ?p ?v } }
WHERE
  { GRAPH  <http://example/bookStore1>
       { ?book dc:date ?date .
         FILTER ( ?date > "1970-01-01T00:00:00-02:00"^^xsd:dateTime )
         ?book ?p ?v
  } }
```

BookStore2 INSERT rule as pipeline



NOTE: Usually several rules would be used in each pipeline stage

```
# Exa
#
PREF
PREF

INSERT
  { GRAPH <http://example/bookStore2> { ?book ?p ?v } }
WHERE
  { GRAPH  <http://example/bookStore1>
      { ?book dc:date ?date .
        FILTER ( ?date > "1970-01-01T00:00:00-02:00"^^xsd:dateTime )
        ?book ?p ?v
  } }
```

BookStore2 pipeline definition

```
@prefix p: <http://purl.org/pipeline/ont#> .
@prefix : <http://localhost/> .
:bookStore1 a p:JenaNode .
:bookStore2 a p:JenaNode ;
    p:inputs ( :bookStore1 ) ;
    p:updater “bookStore2-updater.sparql” .
```

SPARQL INSERT as a reusable rule: bookStore2-updater.sparql

```
# $output will be the named graph for the rule's results
# $input1 will be the input named graph
PREFIX dc:  <http://purl.org/dc/elements/1.1/>
PREFIX xsd: <http://www.w3.org/2001/XMLSchema#>

INSERT
  { GRAPH <http://example/bookStore2> { ?book ?p ?v } }
WHERE
  { GRAPH <http://example/bookStore1>
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        ?book ?p ?v
 } }
```
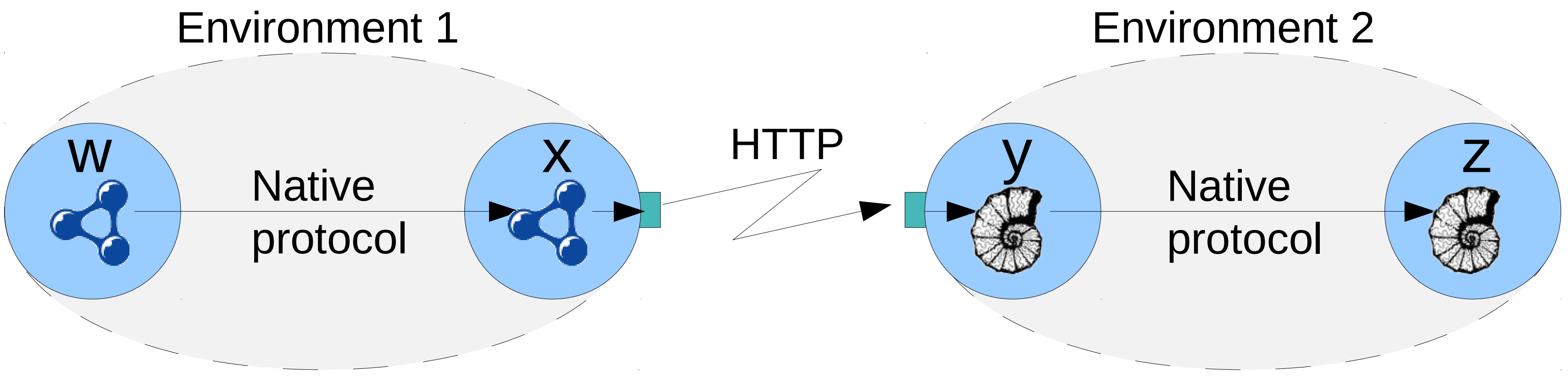

Why RDF pipeline definition?

- **Graphs are natural to RDF**
- **Permits inferencing**
- **Easy visualization**
- **Efficiency . . .**

Logical pipeline communication

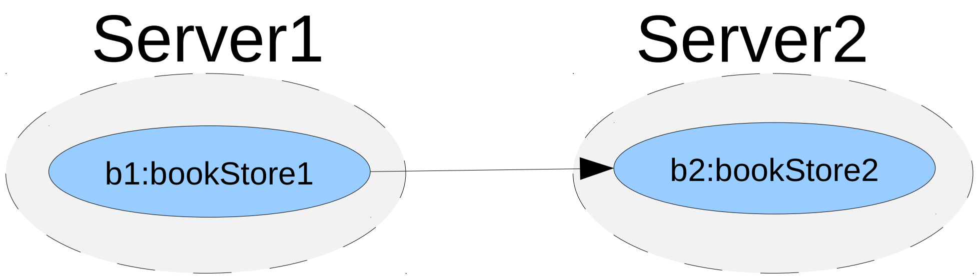
- **Uniform interface: RESTful HTTP**

Physical pipeline communication: efficiency



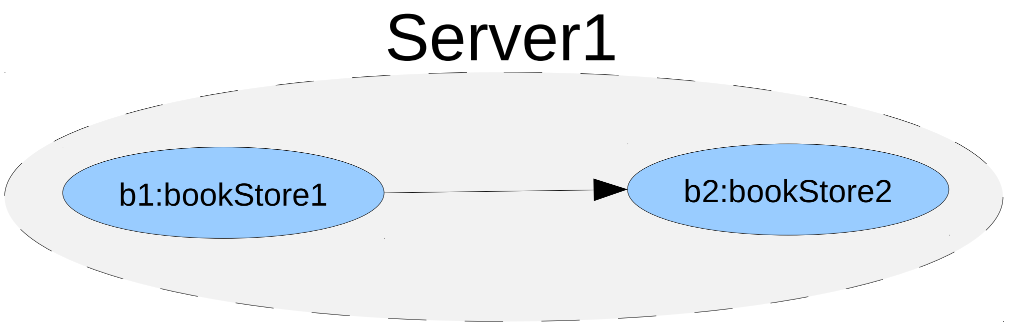
- **Wrappers can transparently:**
  - **Use native protocols <u>within</u> an environment**
  - **Use HTTP <u>between</u> environments**
- **Example:**
  - **Inferencing from one named graph to another in an RDF store**

BookStore pipeline across servers




```
1.  @prefix p: <http://purl.org/pipeline/ont#> .
2.  @prefix b1: <http://server1/> .
3.  @prefix b2: <http://server2/> .
4.  b1:bookStore1 a p:JenaNode .
5.  b2:bookStore2 a p:JenaNode ;
6.      p:inputs ( b1:bookStore1 ) ;
7.      p:updater “bookStore2-updater.sparql” .
```

BookStore pipeline within one server



1. **@prefix p: <http://purl.org/pipeline/ont#> .**
2. **@prefix b1: <http://server1/> .**
3. **@prefix b2: <http://server1/> .**
4. **b1:bookStore1 a p:JenaNode .**
5. **b2:bookStore2 a p:JenaNode ;**
6. **p:inputs (b1:bookStore1) ;**
7. **p:updater “bookStore2-updater.sparql” .**

Incremental update of graph collections

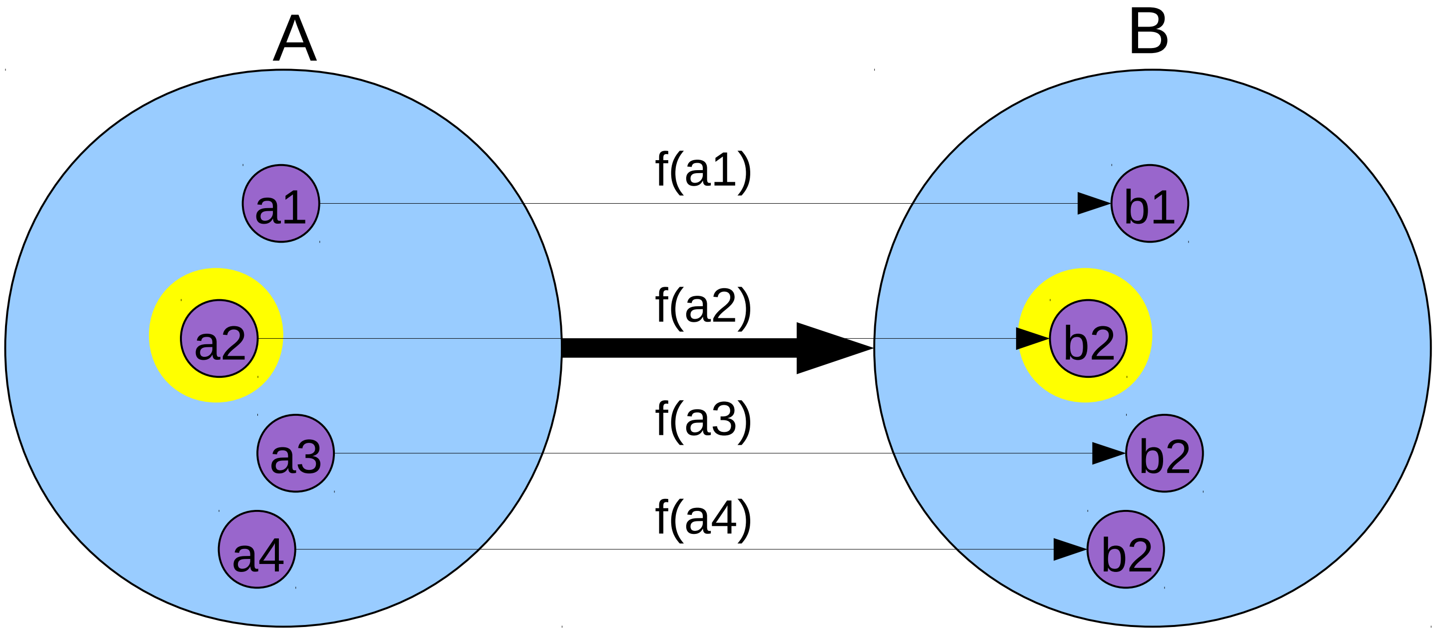
- **Problem: Big datasets take too long to re-generate**
  - **E.g., ~200k patient records can take many hours**
  - **Want to update only what <u>needs</u> to be updated**

- **Big datasets are often composed of many (independent) subgraphs**
  - **E.g., one named graph per patient record**

- **One solution: Update only the subgraphs that changed**

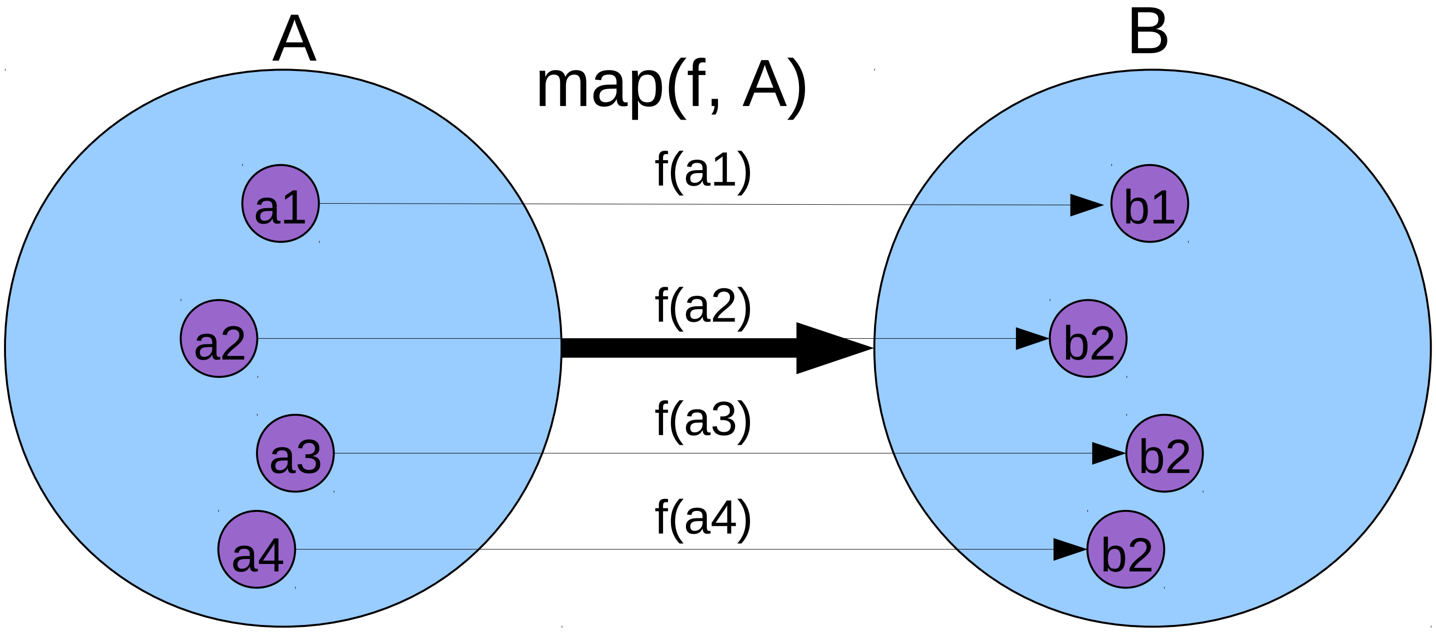
- ***How?***

Generating one graph collection from another



- **A and B contain a large number of items**
- **Each item in A corresponds to one item in B**
- **The same function f creates each bi from ai**
- **Wasteful to regenerate every bi when only a few ai's have changed**

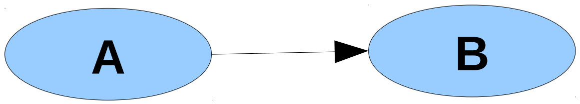
Collection generation as a mapping



- **“Map” function applies f to each item in A**
- **B is updated from A by map(f, A):**

  For each i, bi = f(ai)

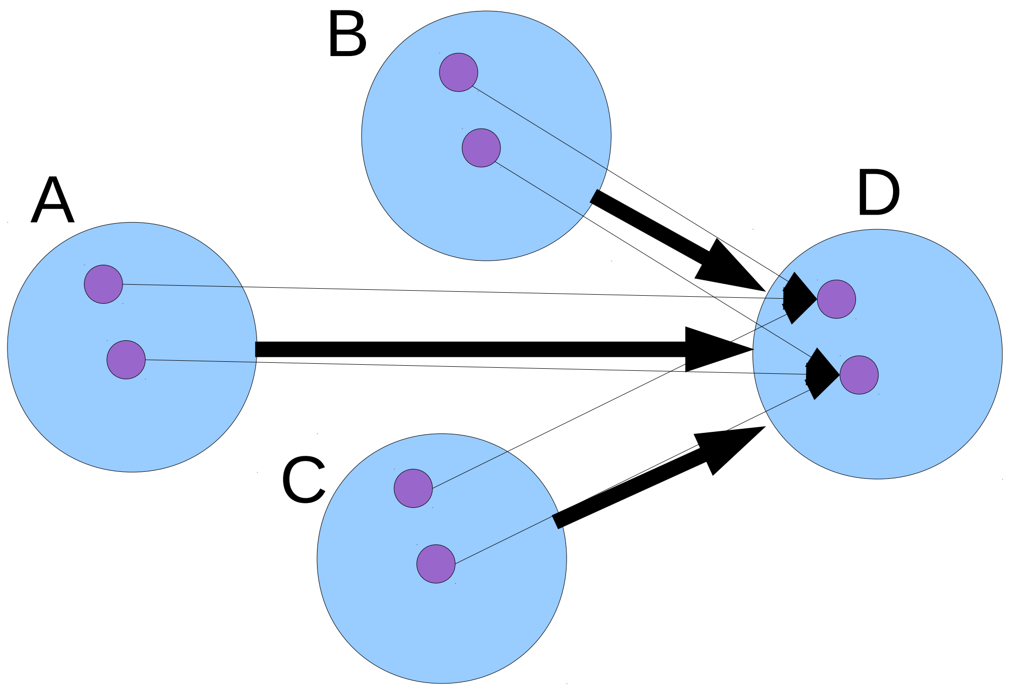
Pipeline definition using map



1. @prefix p: <http://purl.org/pipeline/ont#> .
2. @prefix : <http://localhost/> .
3. :A a p:SesameNode .
4. :B a p:SesameNode ;
5. p:inputs (:A) ;
6. p:updater (p:map "B-updater.sparql") .

Updater needs no logic for incremental update!

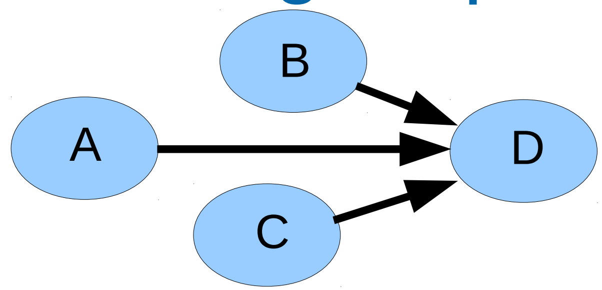
Map with multiple inputs



- **Map can also be used with multiple inputs**
- **D is updated by map(f, A, B, C):**

  For each i, di = f(ai, bi, ci)

Pipeline definition using map with multiple inputs



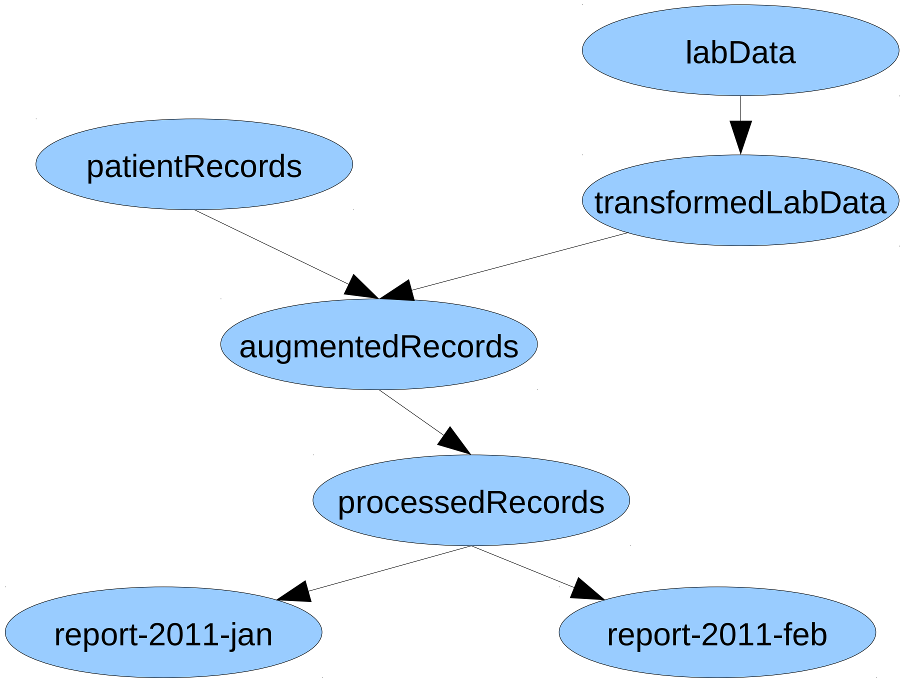
1. @prefix p: <http://purl.org/pipeline/ont#> .
2. @prefix : <http://localhost/> .
3. :A a p:SesameNode .
4. :B a p:SesameNode .
5. :C a p:SesameNode .
6. :D a p:SesameNode ;
7.   p:inputs (:A :B :C) ;
8.   p:updater (p:mapcar "D-updater.sparql") .

Issue: Need for virtual graphs

- **How to query against a large collection of graphs?**
- **Some graph stores query the merge of all named graphs by default**
  - **Virtual graph or "view"**
  - **sd:UnionDefaultGraph feature**
- ***BUT* it only applies to the default graph of the entire graph store**

- ***Conclusion: Graph stores should support multiple virtual graphs***
  - ***Some do, but not standardized***

Motivation for update policies

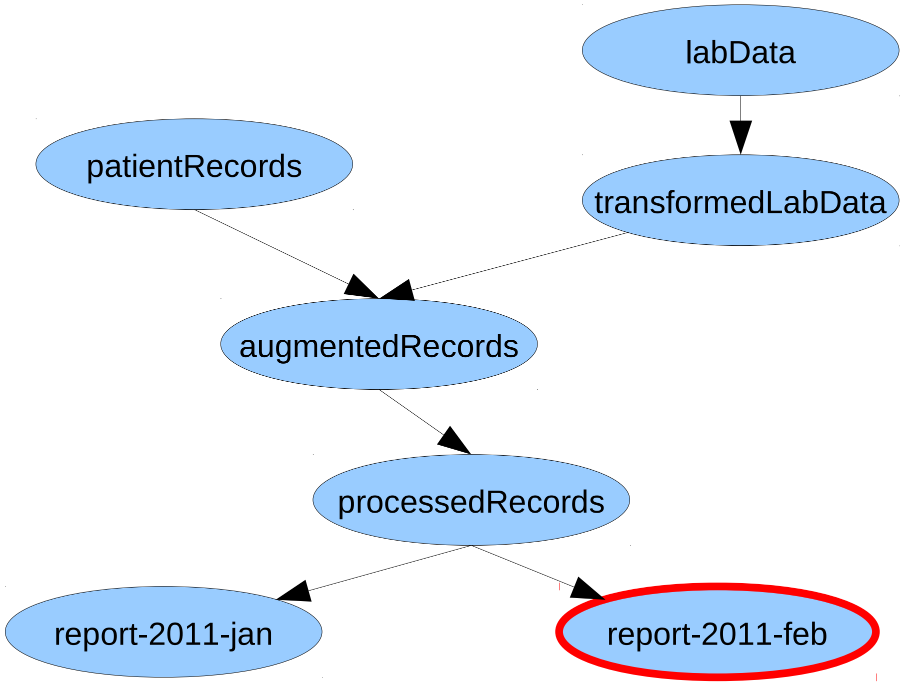


- **<u>When</u> should a node be updated? E.g., processedRecords**
  - **Whenever patientRecords or labData changes? (Eager)**
  - **Only when a report is requested? (Lazy)**
- **Trade-off: Latency versus processing time**

Why wrappers? Update policies

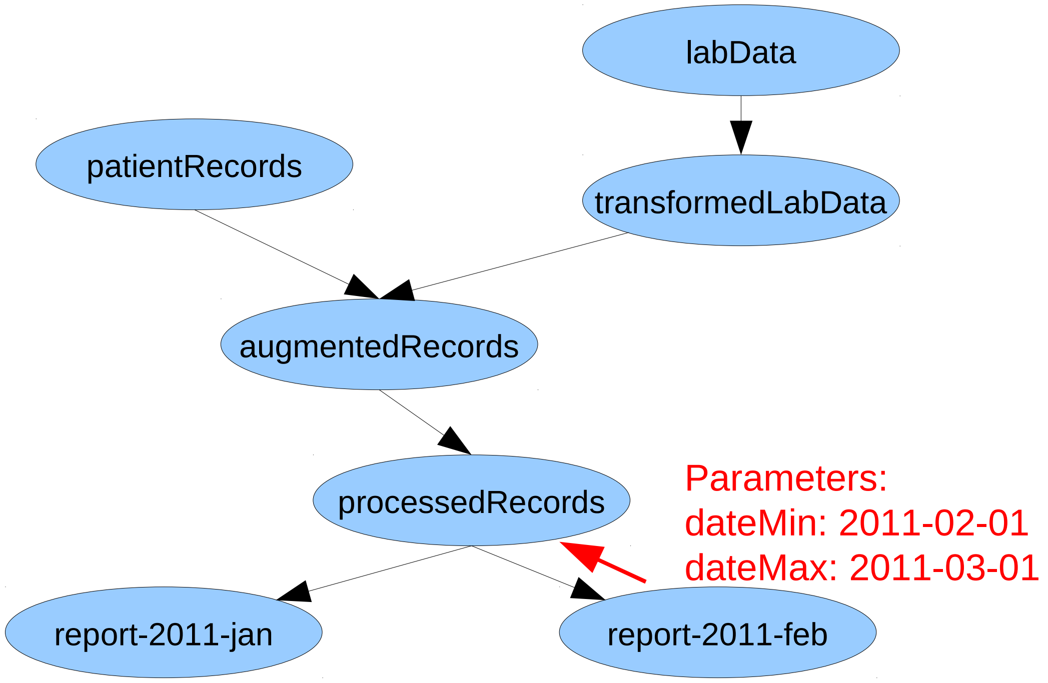
- **Update policy controls <u>when</u> a node's data is updated:**
  - **lazy – When output is requested**
  - **eager – When any of the node's inputs changes**
  - **periodic – Every *n* seconds**
  - **eagerThrottled – When an input changes and the node has not been updated within the past *n* seconds**
  - **Etc.**
- **Handled by wrapper – independent of node update logic**

Problem: How to indicate what data is wanted?



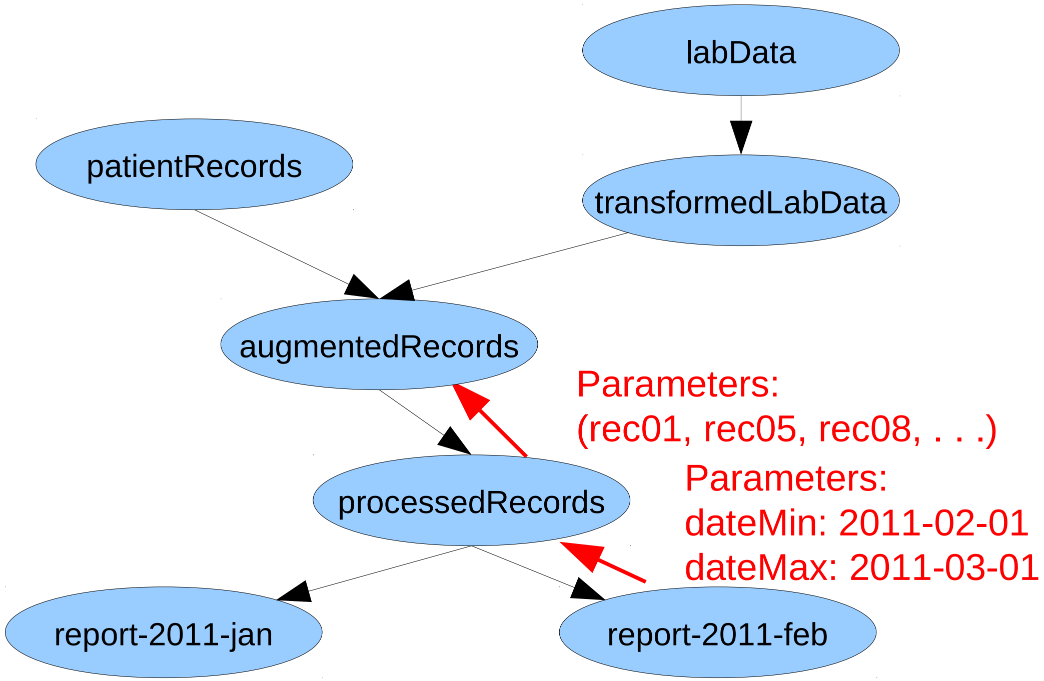
- **report-2010-feb only needs a subset of processedRecords**
- **How can it tell processedRecords what date range it wants?**

Solution: Propagate parameters upstream



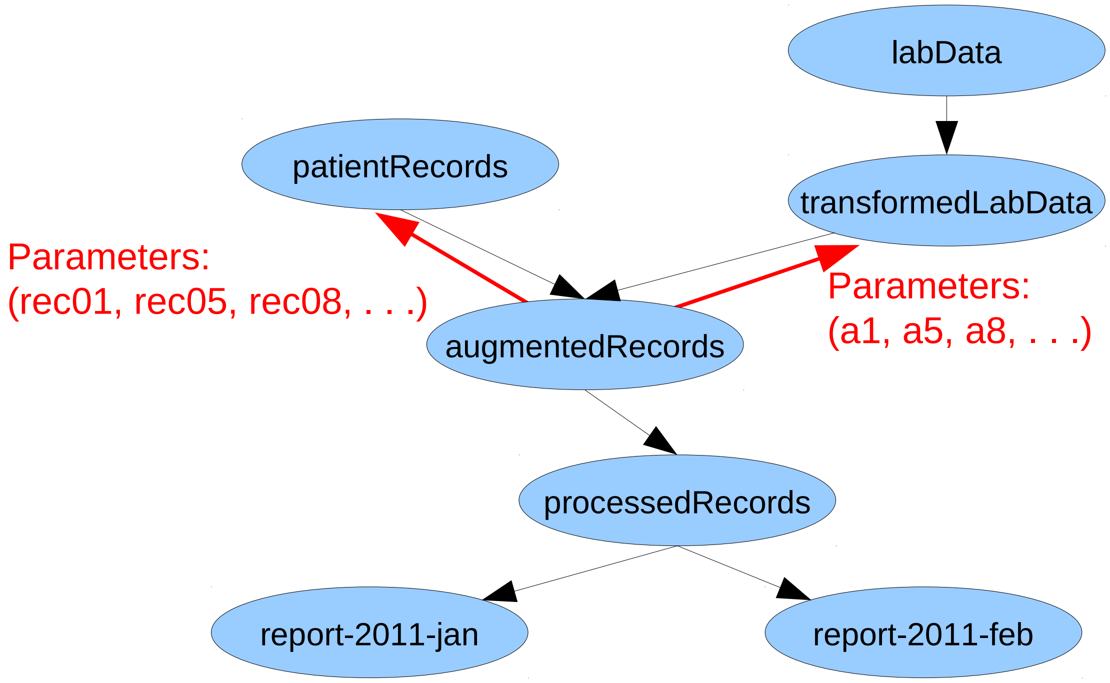
- **dateMin and dateMax parameters are passed <u>upstream</u>**

Propagating parameters upstream



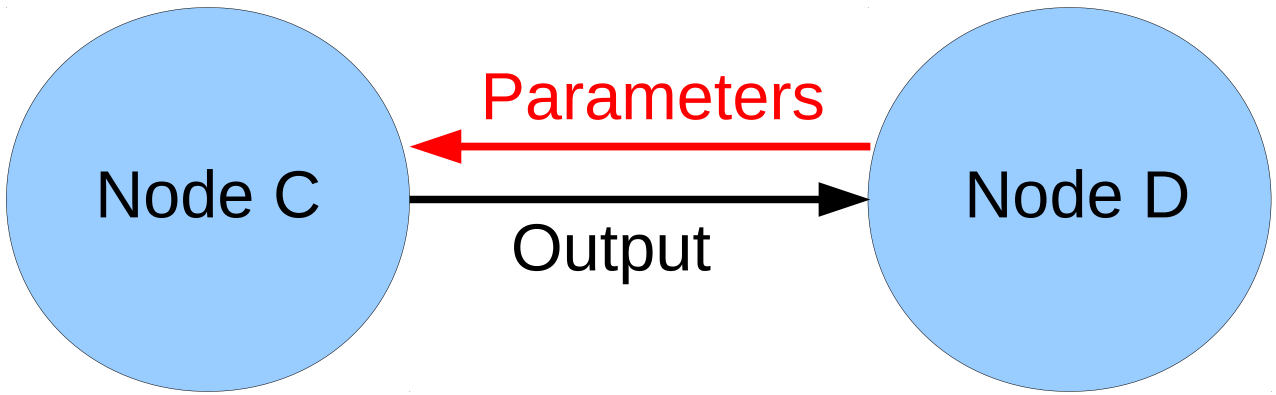
- **Different parameters may be needed by different stages**

Propagating parameters upstream



- **Different parameters may be needed by different inputs**

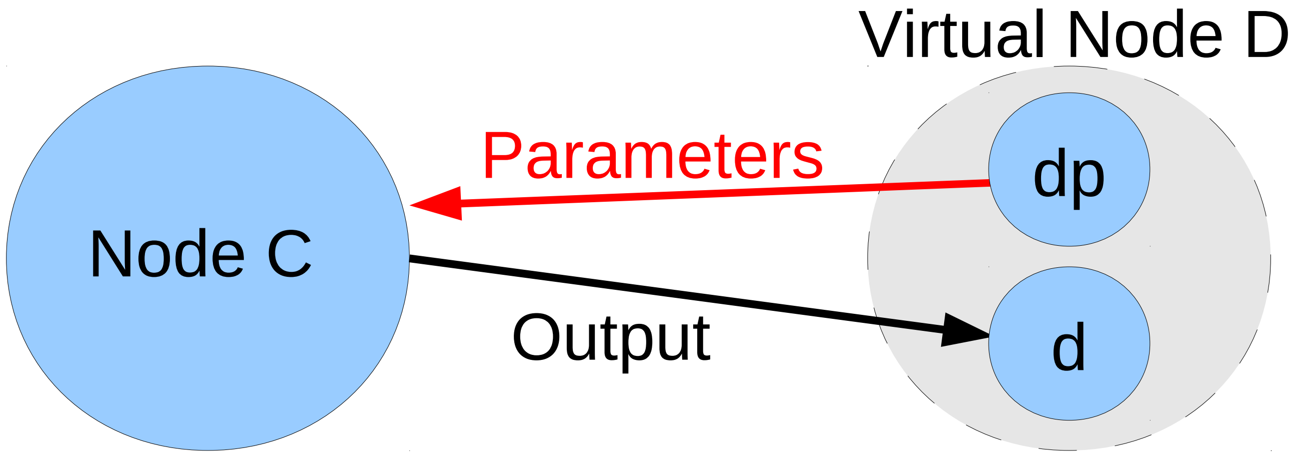
Terminology: output versus parameters



- **Output flows <u>downstream</u>**
- **Parameters flow <u>upstream</u>**

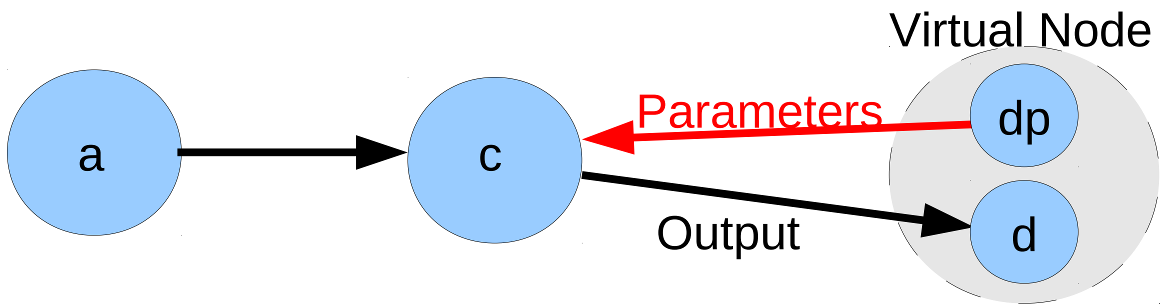
- ***How?***

Parameter nodes



- **Parameters can be achieved by an extra node**
  - **Virtual node D consists of two physical nodes: d, dp**
- **Parameter node (dp) is no different than other nodes, but <u>used</u> as a parameter node by C.**
- **Parameter nodes are like additional input nodes**

Pipeline definition with parameter



1. @prefix p: <http://purl.org/pipeline/ont#> .
2. @prefix : <http://localhost/> .
3. :a a p:Node .
4. :c a p:Node ;
5. p:inputs (:a) ;
6. p:parameters (:dp) ;
7. p:updater "c-updater" .
8. :d a p:Node ;
9. p:updater "d-updater" .
10. :dp a p:Node .

Rough sketch of pipeline ontology: ont.n3 (1)

```
@prefix p: <http://purl.org/pipeline/ont#> .
@prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#> .

######### Example Node types ##########
p:Node a rdfs:Class .
p:CommandNode  rdfs:subClassOf p:Node .  # Default Node type
p:JenaNode      rdfs:subClassOf p:Node .
p:SesameNode    rdfs:subClassOf p:Node .
p:PerlNode      rdfs:subClassOf p:Node .
p:MysqlNode rdfs:subClassOf p:Node .
p:OracleNode  rdfs:subClassOf p:Node .
```

Rough sketch of pipeline ontology: ont.n3 (2)

```
######### Node properties ##########
p:inputs    rdfs:domain p:Node .
p:parameters  rdfs:domain p:Node .
p:dependsOn   rdfs:domain p:Node .

# p:output specifies the output cache for a node.
# It is node-type-specific, e.g., filename for FileNode .
# It may be set explicitly, otherwise a default will be used.
p:output rdfs:domain p:Node .

# p:updater specifies the updater method for a Node.
# It is node-type-specific, e.g., a script for CommandNode .
p:updater   rdfs:domain p:Node .

# p:updaterType specifies the type of updater used.
# It is node-type-specific.
p:updaterType rdfs:domain p:Node .
```

Rough sketch of pipeline ontology: ont.n3 (3)

```
29.######### Rules ##########
13.# A Node dependsOn its inputs and parameters:
14.{ ?a p:inputs ?b . }     => { ?a p:dependsOn ?b . } .
15.{ ?a p:parameters ?b . } => { ?a p:dependsOn ?b . } .
```

Summary

- **Flexible:**
  - **Any kind of data – not only RDF**
  - **Any kind of custom code (using wrappers)**
  - **Internal homogeneous pipelines**
  - **Distributed heterogeneous pipelines**
- **Efficient**
  - **Updates only what <u>needs</u> to be updated**
  - **Communicates with native protocols when possible, HTTP otherwise**
- **Easy:**
  - **Easy to implement nodes (using standard wrappers)**
  - **Easy to define pipelines (using a few lines of RDF)**
  - **Easy to visualize**
  - **Easy to maintain – very loosely coupled**

Questions?

BACKUP SLIDES

Nodes

- **Each node has:**
  - **A <u>URI</u> (to identify it)**
  - **One output "<u>cache</u>"**
  - **An <u>update method</u> ("updater") for refreshing its output cache**
- **A node may also have:**
  - **<u>Inputs</u> (from upstream)**
  - **<u>Parameters</u> (from downstream)**

Basic node functions

- **Update cache**
  - **Triggered by an input or parameter change**
  - **Changes the state of the node**
  - **Handled by custom logic “updater” method**
- **Serve an output request**
  - **Triggered by GET request**
  - **Normally handled by wrapper**
  - **Does not (normally) change the state of the node**
-

Output cache

- **One per node**
  - **All downstream nodes see the same data**
- **Logical data store, e.g.:**
  - **Named graph within an RDF store**
  - **File**
  - **Database**
- **Not necessarily physical**
  - **Different nodes may share the same physical store**
- **Has an associated lastModified datetime**
- **Allows the node to serve data without re-running its updater**

Example: Node

- **Updater is an arbitrary command script**
- **Output data cached as a file**
- **Command script is invoked as:**

  cmd thisUri [i1 i2 ...] [p1 p2 ...] > cacheFile

- **Where:**
  - ***cmd* – Command to invoke to update *cacheFile***
  - ***thisUri* – URI of this node**
  - ***i1, i2, …* – Cache filenames from input nodes**
  - ***p1, p2, …* – Cache filenames from parameter nodes**
  - ***cacheFile* – Cache file for thisUri node**

(Demo 0: Hello world)

Example: JenaNode

- **Output data cached as a <u>named graph</u>**
- **Updated by:**
  - **Sparql INSERT**
  - **Rules**
  - **Reasoner**
  - **Java function**
- **p:updaterType can specify the type of updater used**

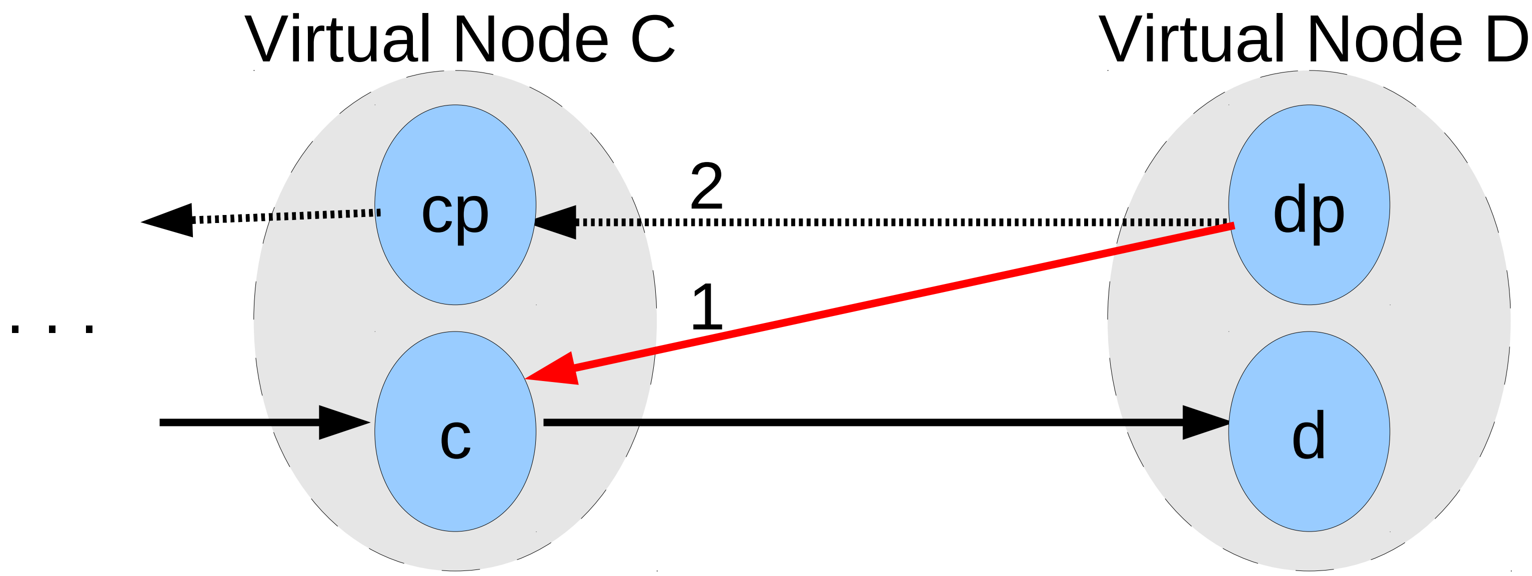
Potential JenaNode definition

```
@prefix p: <http://purl.org/pipeline/ont#> .
@prefix : <http://localhost/> .
:e a :JenaNode ;
   p:updater “e-updater.sparql” .
```

File example-construct.txt

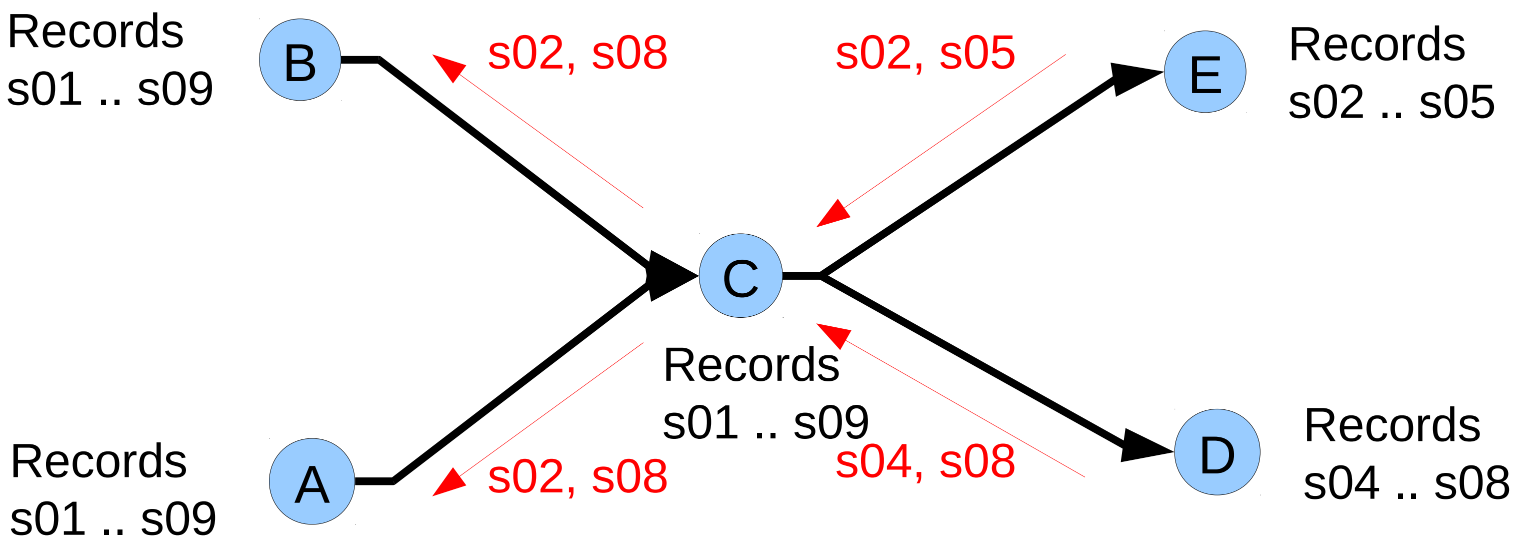
```
# Example from SPARQL 1.1 spec
PREFIX foaf:    <http://xmlns.com/foaf/0.1/>
PREFIX vcard:   <http://www.w3.org/2001/vcard-rdf/3.0#>

CONSTRUCT { ?x  vcard:N _:v .
            _:v vcard:givenName ?gname .
            _:v vcard:familyName ?fname }
WHERE
 {
   { ?x foaf:firstname ?gname } UNION  { ?x foaf:givenname   ?gname } .
   { ?x foaf:surname   ?fname } UNION  { ?x foaf:family_name ?fname } .
 }
```

Propagating parameters upstream



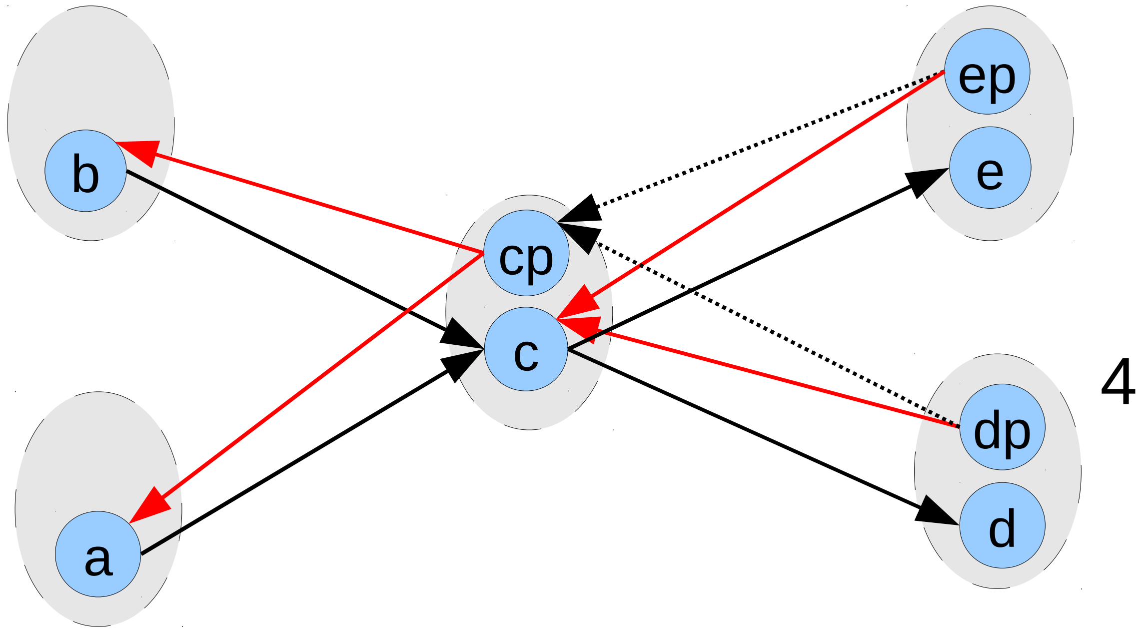
- **Parameter nodes are data sources for <u>two purposes</u>:**
  - **1. Additional input to regular node (in computing output)**
  - **2. Propagating parameters farther upstream**

Example 2: Passing parameters upstream

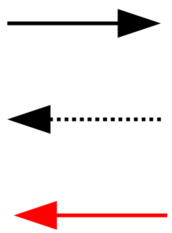


- **Node C may hold more records than D&E want**
- **Nodes D&E pass parameters upstream:**
  - **Min, max record numbers desired**
- **Node C supplies the <u>union</u> of what D&E requested**
- **Nodes D&E select the subsets they want: s04..s08 and s02..s05**
- **Node C, in turn, passes parameters to nodes A&B**

Example 2: Passing parameters upstream



- **Legend:**



Regular node output to regular node input

Param node output to param node input

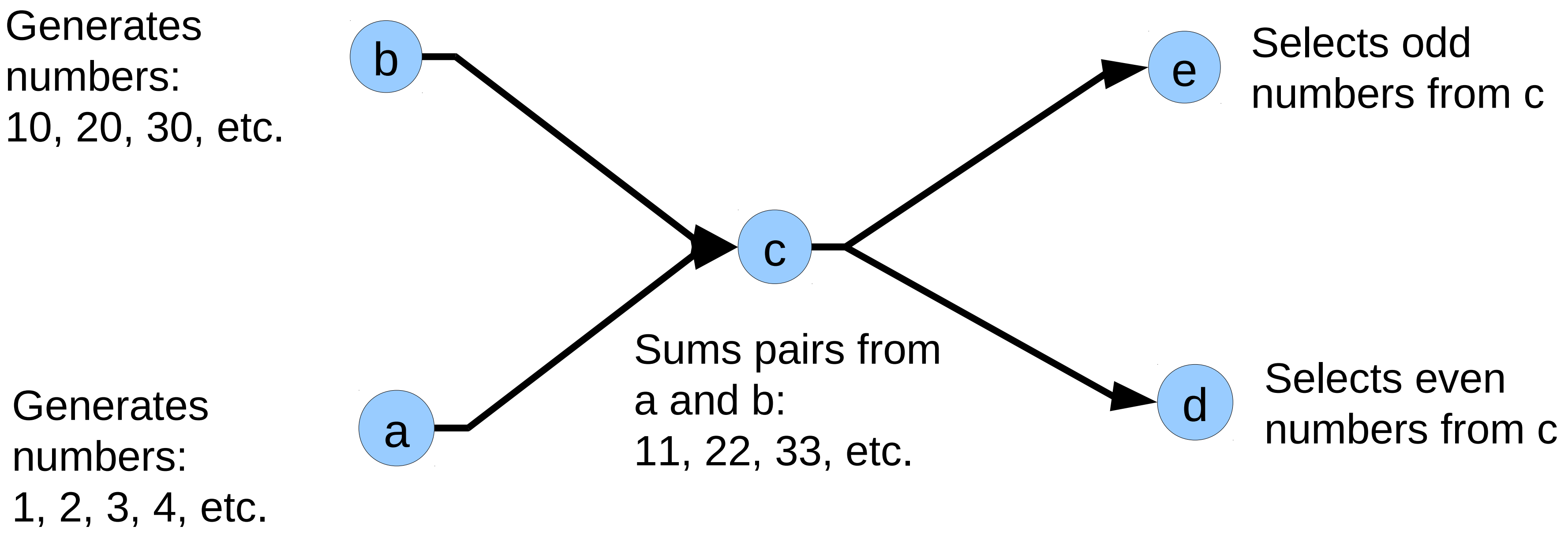
Param node output to regular node param

Example 2: Pipeline with parameters in N3

```
:a      p:cache "a-cache.txt" .
:a      p:updater "a-updater" .
:a      p:parameters ( :cp ) .

:b      p:cache "b-cache.txt" .
:b      p:updater "b-updater" .
:b      p:parameters ( :cp ) .

:c      p:cache "c-cache.txt" .
:c      p:updater "c-updater" .
:c      p:inputs ( :a :b ) .
:c      p:parameters ( :dp :ep ) .
:cp     p:cache "cp-cache.txt" .
:cp     p:updater "cp-updater" .
:cp     p:inputs ( :dp :ep ) .

:d      p:cache "d-cache.txt" .
:d      p:updater "d-updater" .
:d      p:inputs ( :c ) .
:dp     p:cache "dp-cache.txt" .

:e      p:cache "e-cache.txt" .
:e      p:updater "e-updater" .
:e      p:inputs ( :c ) .
:ep     p:cache "ep-cache.txt" .
```

(Demo: Sparql INSERT)

Example 1: Multiple nodes



- **Node c consumes records from a & b**
- **Nodes d & e consume records from c**

Data in node a

<s01> <a1> 111 .

<s01> <a2> 121 .

<s01> <a3> 131 .

<s02> <a1> 112 .

<s02> <a2> 122 .

<s02> <a3> 132 .

<s03> <a1> 113 .

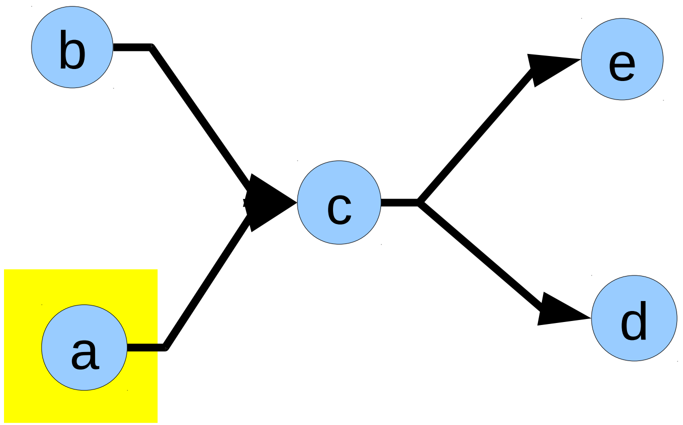
<s03> <a2> 123 .

<s03> <a3> 133 .

<s04> <a1> 114 .

. . .

<s09> <a3> 139 .



Data in node b

<s01> <b1> 211 .

<s01> <b2> 221 .

<s01> <b3> 231 .

<s02> <b1> 212 .

<s02> <b2> 222 .

<s02> <b3> 232 .

<s03> <b1> 213 .

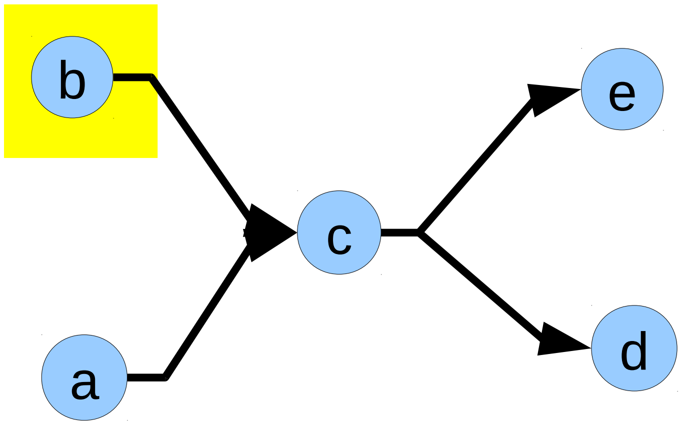
<s03> <b2> 223 .

<s03> <b3> 233 .

<s04> <b1> 214 .

. . .

<s09> <b3> 239 .



Data in node c

<s01> <a1> 111 .

<s01> <a2> 121 .

<s01> <a3> 131 .

<s01> <b1> 211 .

<s01> <b2> 221 .

<s01> <b3> 231 .

Merged triples

<s01> <c1> 111211 .

<s01> <c2> 121221 .

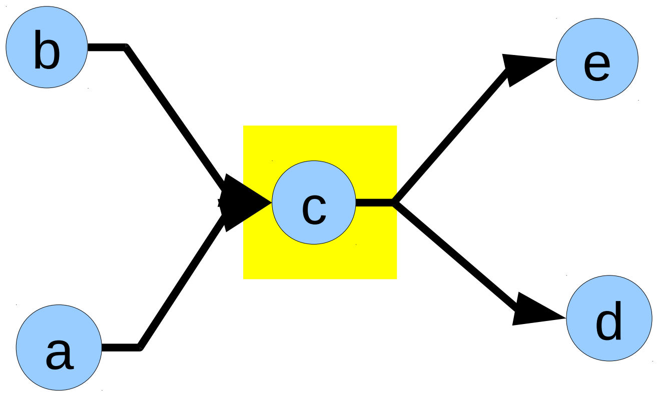
<s01> <c3> 131231 .

Inferred triples

<s02> <a1> 112 .

. . .

<s09> <c3> 139239 .



Data in nodes d&e: same as c

<s01> <a1> 111 .

<s01> <a2> 121 .

<s01> <a3> 131 .

<s01> <b1> 211 .

<s01> <b2> 221 .

<s01> <b3> 231 .

<s01> <c1> 111211 .

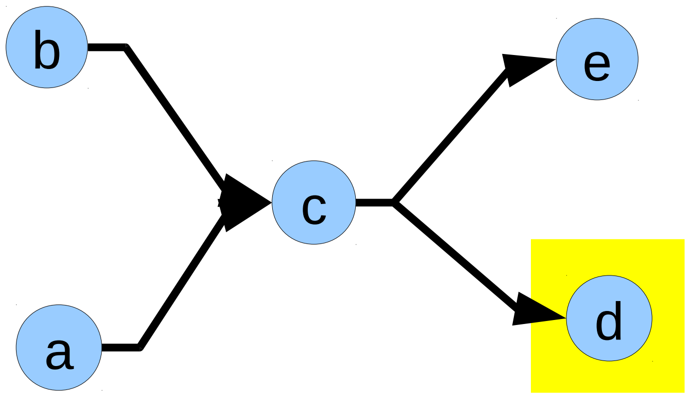
<s01> <c2> 121221 .

<s01> <c3> 131231 .

<s02> <a1> 112 .

. . .

<s09> <c3> 139239 .



Example 2: Multiple node pipeline in N3

```
# Example 1: Multiple nodes

@prefix p: <http://purl.org/pipeline/ont#> .
@prefix : <http://localhost/> .

:a a p:Node .
:a    p:updater "a-updater" .

:b a p:Node .
:b    p:updater "b-updater" .

:c a p:Node .
:c    p:inputs ( :a :b ) .
:c    p:updater "c-updater" .

:d a p:Node .
:d    p:inputs ( :c ) .
:d    p:updater "d-updater" .

:e a p:Node .
:e    p:inputs ( :c ) .
:e    p:updater "e-updater" .
```

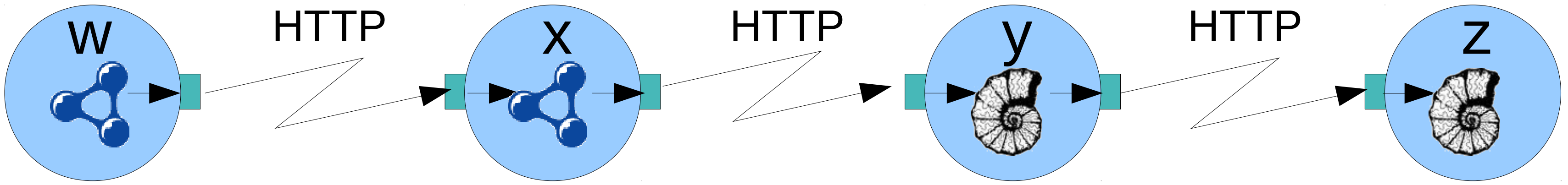
(Demo 1: Multiple node pipeline)

Optimizing internal communication

Inter-node communication: Logical view

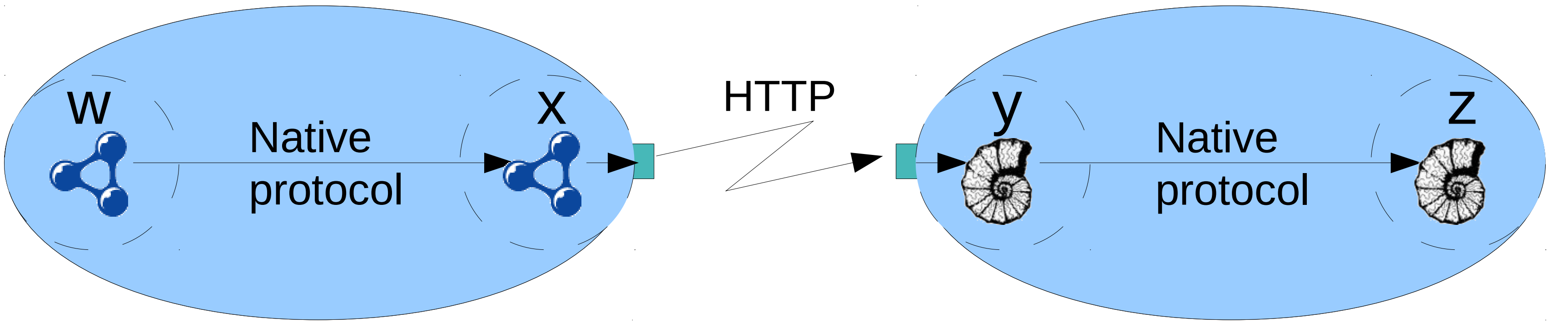
- **Nodes pass data from one to another . . .**
  - **But *how*?**

Physical view - Unoptimized



- **Framework handles inter-node communication**
  - **Uniform virtual interface makes communication easy**
- **By default, nodes use HTTP**
  - **Common denominator**

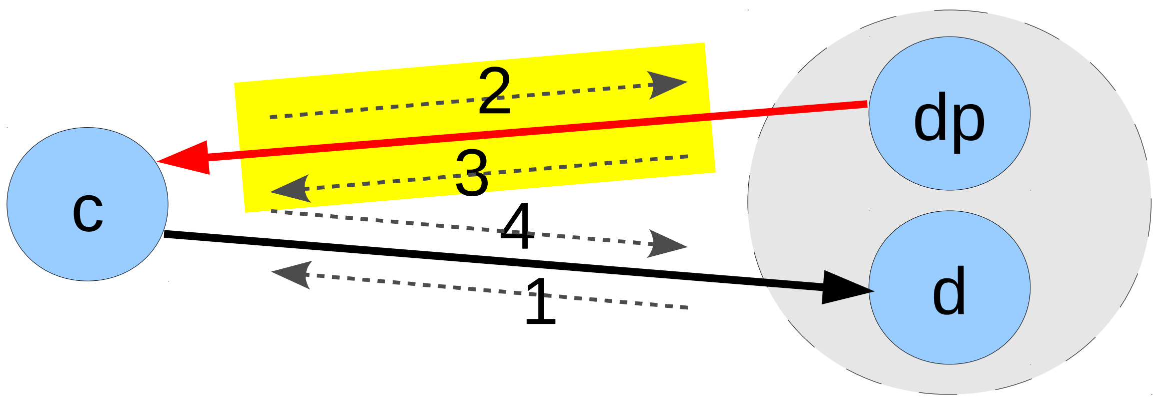
Physical view - Optimized



- **But nodes that share an implementation environment communicate directly, using native protocol, e.g.:**
  - **One SesameNode to another in the same RDF store**
  - **One Node to another on the same server**
- **Wrappers handle both native protocol and HTTP**

Optimizing external communication

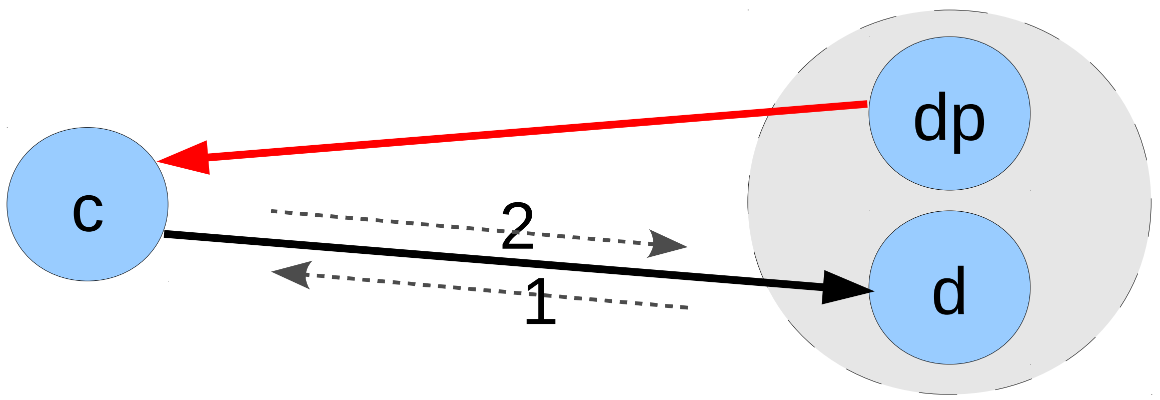
Optimizing HTTP GET with parameter node



- **Suppose node d has parameter node dp**
- **When d needs to GET data from c, c must first GET parameter data from dp:**
  1. **Request: d sends GET request to c**
  2. **Request: c sends GET request to dp**
  3. **Response: dp responds to c**
  4. **Response: c responds to d**

} Extra round trip (steps 2–3)

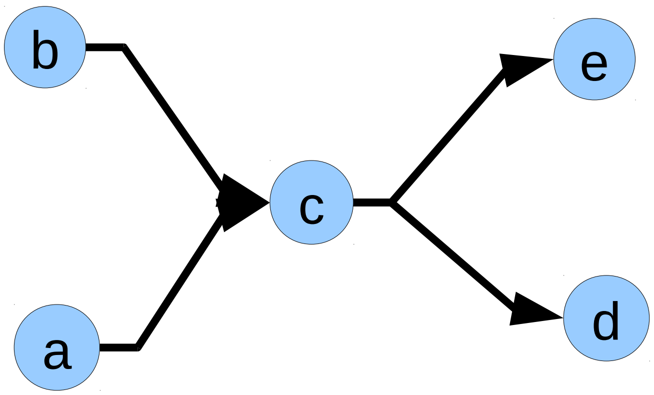
Optimized HTTP GET with parameter node



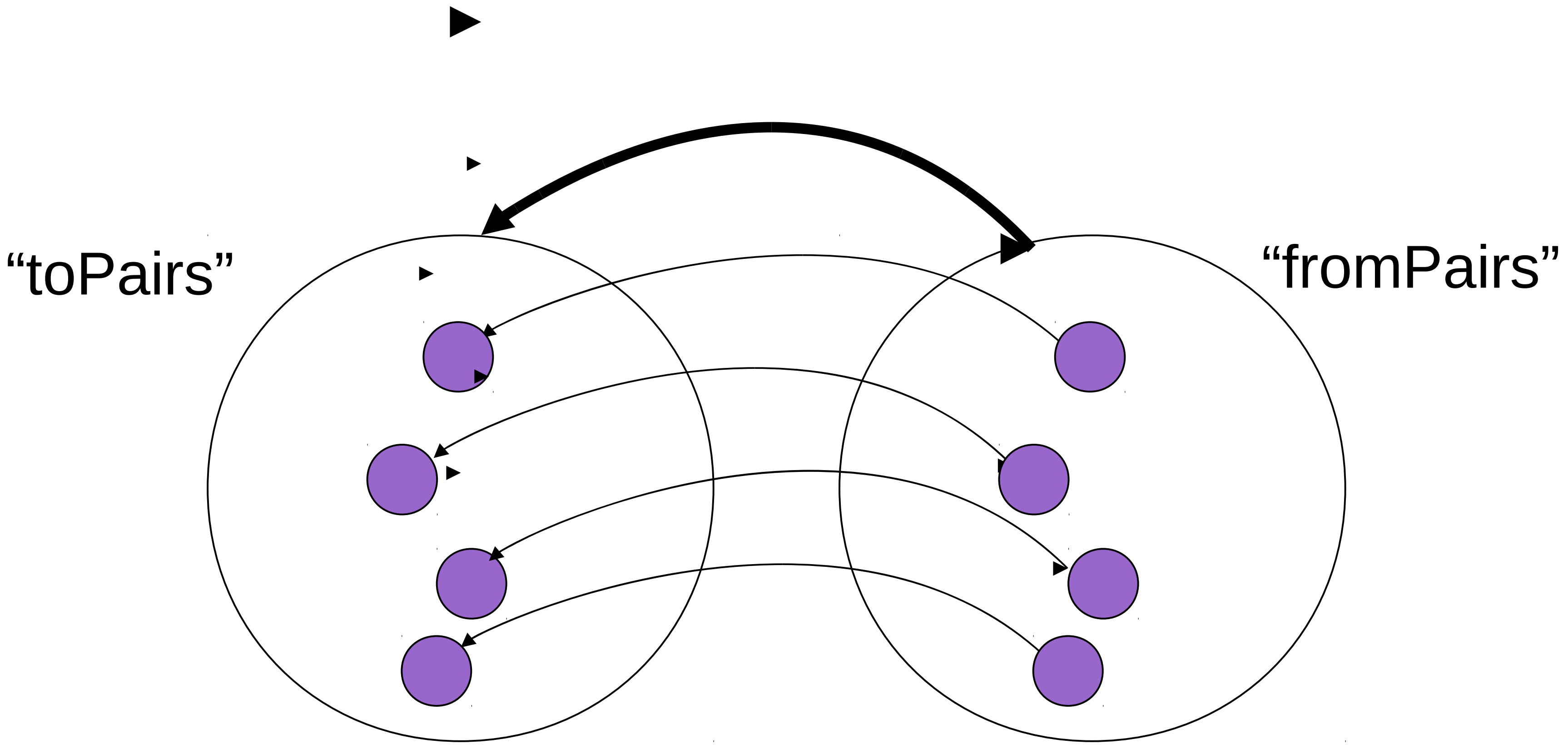
- **To optimize, d can send dp response *preemptively* to c with its GET request**
- **Query parameters can include:**
  - **Node URI of dp**
  - **Last-Modified, ETag, Content-Type, Body, etc.**
- **I.e., the same response info as if c had issued a GET request to dp**

[Thanks to Steve Battle for inspiring this optimization]

Small diagram



fromPairs and toPairs



- **Transformation from fromPairs to toPairs**

Logic for mapcar update

```
function MapcarUpdate(Method method,
                    Pairs toPairs, Pairs fromPairs) {
  foreach Key k in keys of fromPairs {
    if !exists(toPairs{k})
        || fromPairs{k}.updateTime > toPairs{k}.updateTime {
      Update(toPairs{k});
    }
  }
}
```

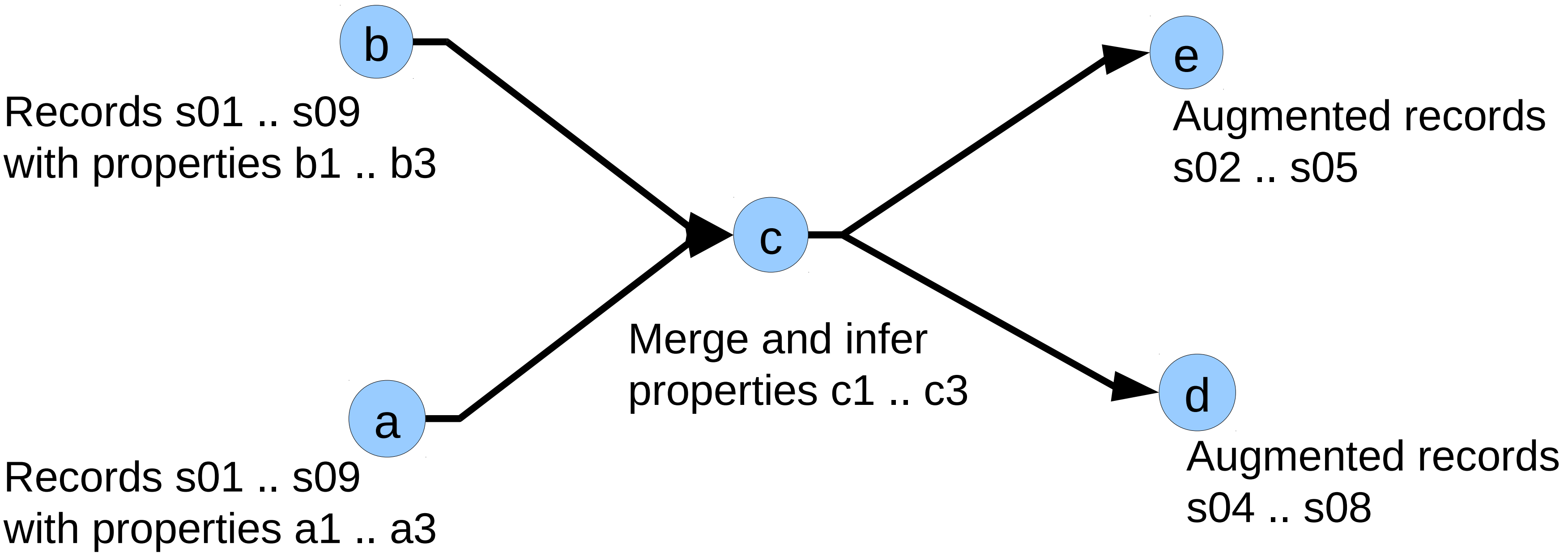
Eager update logic

```
/* Called after parent is updated */
function EagerUpdate(PCache parent) {
  foreach PCache child that depends on parent {
    child.update();
    EagerUpdate(child);
  }
}
```

Lazy update logic

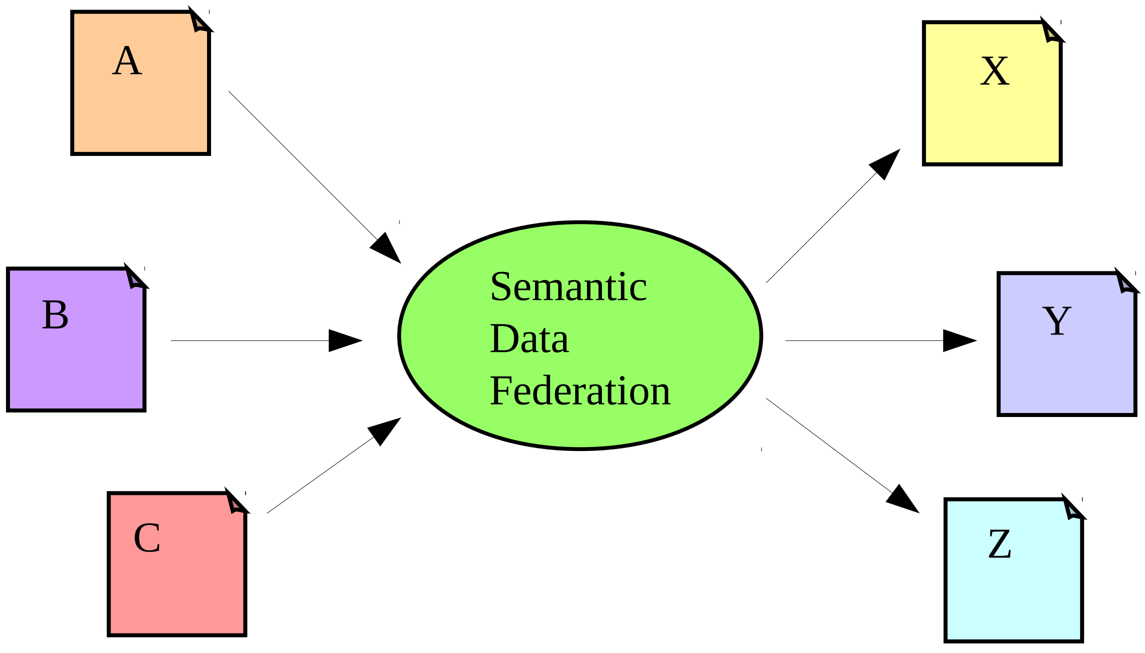
```
/* Called before getting data from child */
function LazyUpdate(PCache child) {
  /* “contributes to” is the inverse of “depends on” */
  foreach PCache parent that contributes to child {
      LazyUpdate(parent);
   }
  if IsOutOfDate(child) then child.update();
}
```

Example 2: merging, inferring



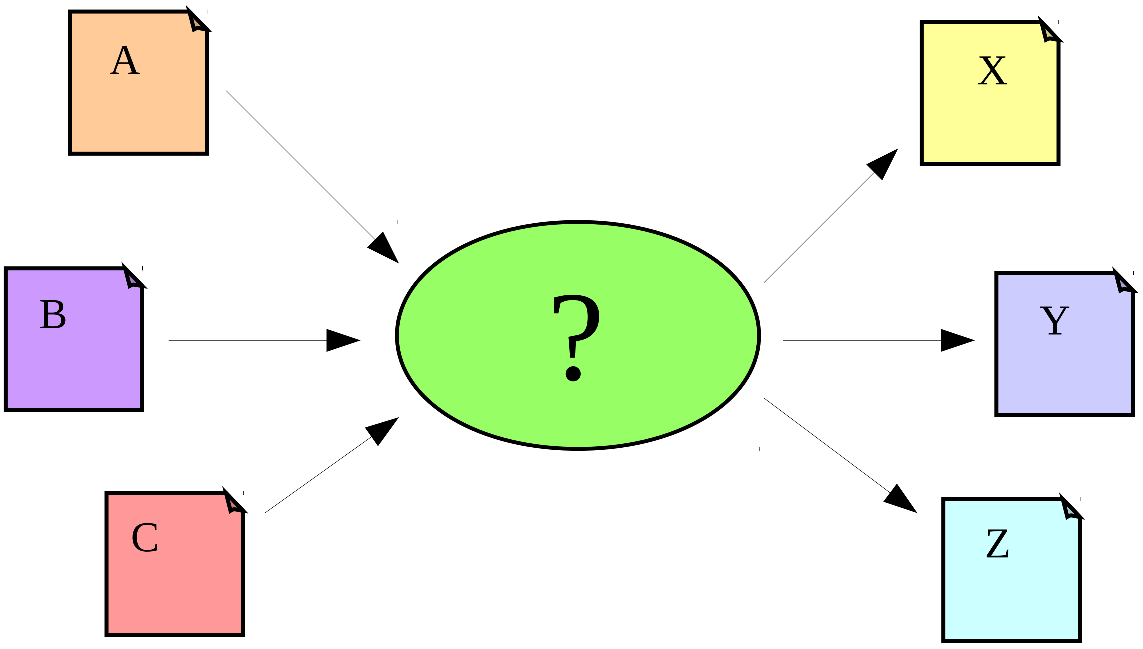
- **Node c merges and augments records**
- **Nodes d&e select subsets**

Semantic Data Federation



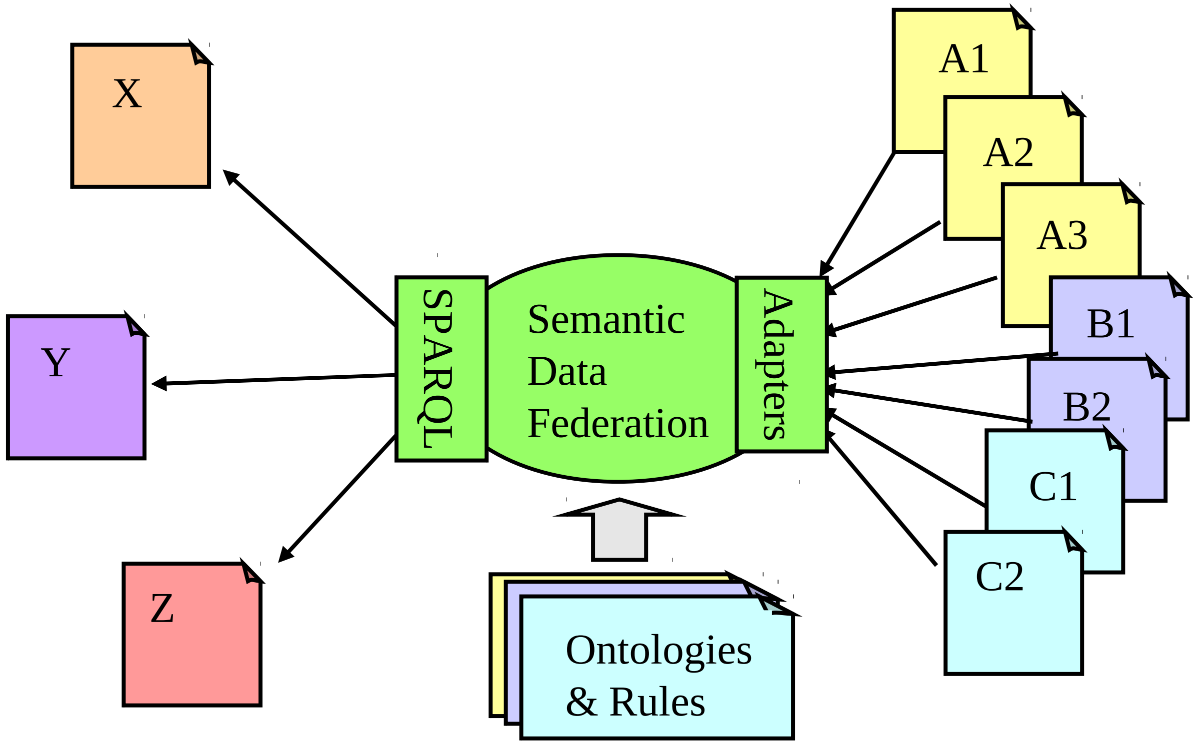
- **Integrating data from diverse:**
  - **vocabularies, formats and data sources**
- **Producing data for diverse:**
  - **vocabularies, formats and applications**

Semantic Data Federation



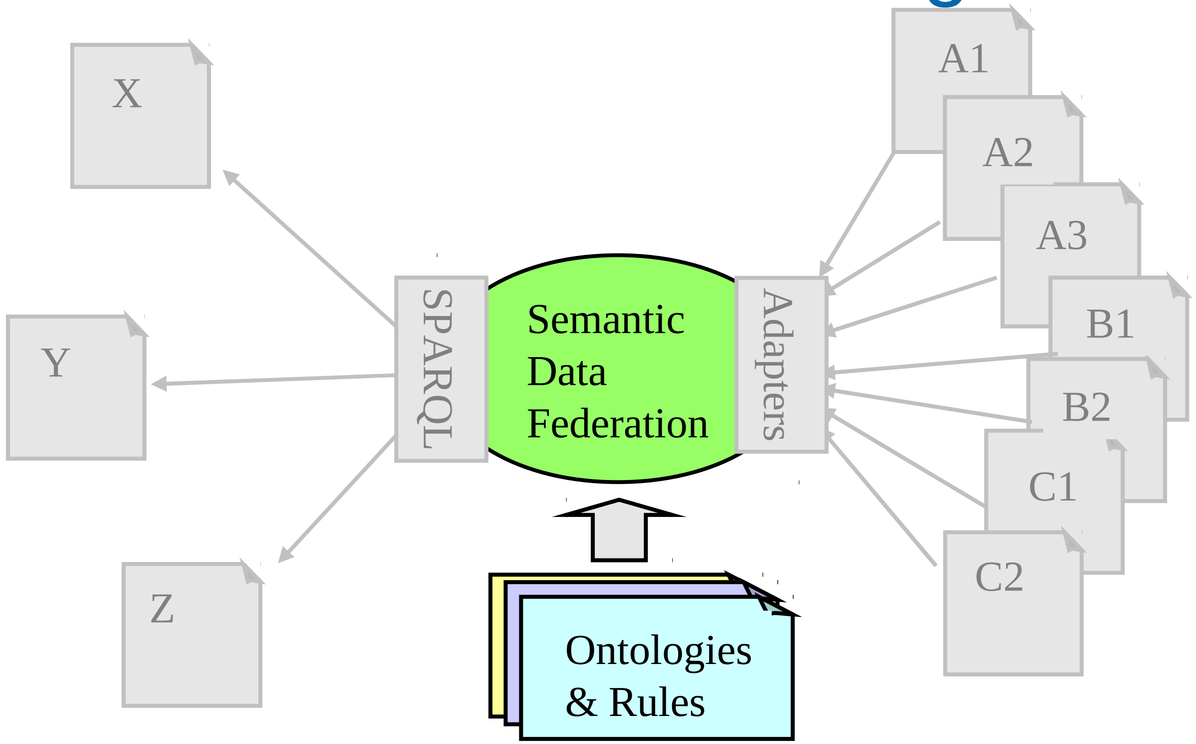
- **Integrating data from diverse:**
  - **vocabularies, formats and data sources**
- **Producing data for diverse:**
  - **vocabularies, formats and applications**

Semantic Data Federation



- **Does transformations, caching, etc.**
- **Different sources use different vocabularies/ontologies**
- **Different consumers use different vocabularies/ontologies**
- **See also:**
  - **SemTech 2009 slides: http://dbooth.org/2009/stc/**
  - **(Draft) paper: http://dbooth.org/2009/query/**

Persistent Caching

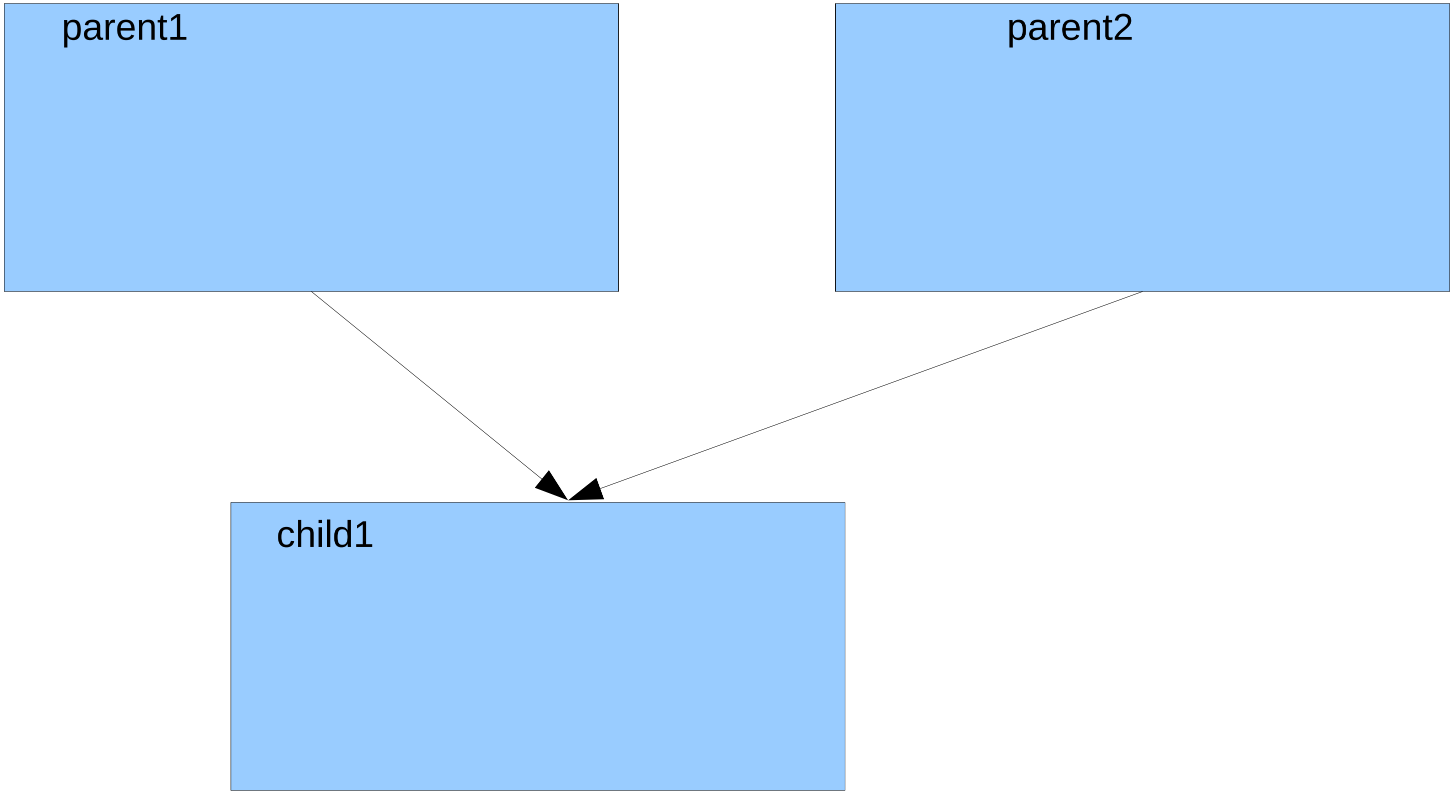


- **Semantic Data Federation does <u>persistent caching</u>**
- **Many pcaches may be used**
- **Each should be updated automatically**

Persistent Cache (pcache)

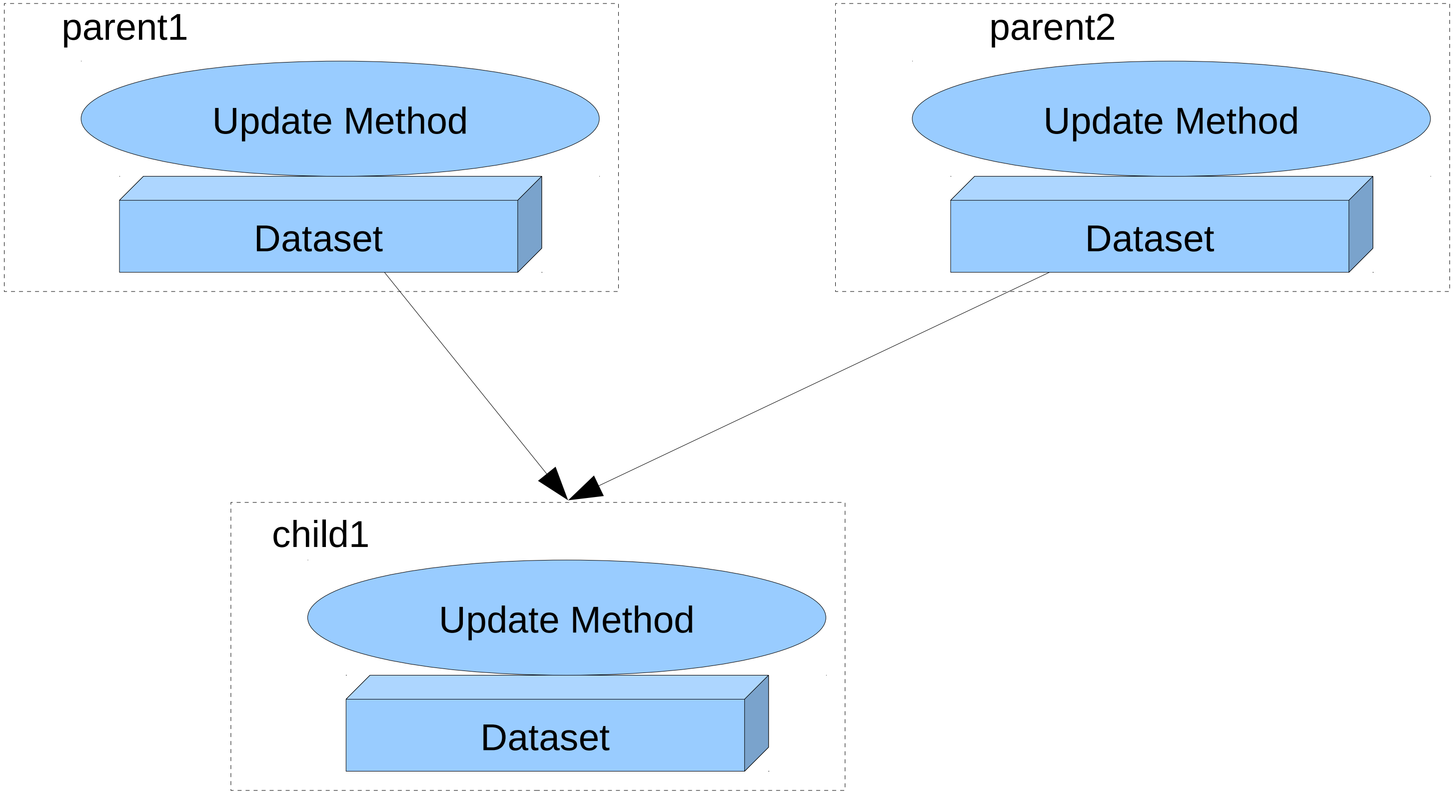
- **Each pcache can be regenerated based on its**
  - **Update method (e.g., SPARQL rules)**
  - **Update policy (eager, periodic, lazy, etc.)**
  - **Dependencies (other pcaches, data sources, ontologies, rules)**
- **Pcache update is like running a makefile:**
  - **Dependencies are analyzed**
  - **Each out-of-date pache is updated based on its update method and update policy**

Dependencies



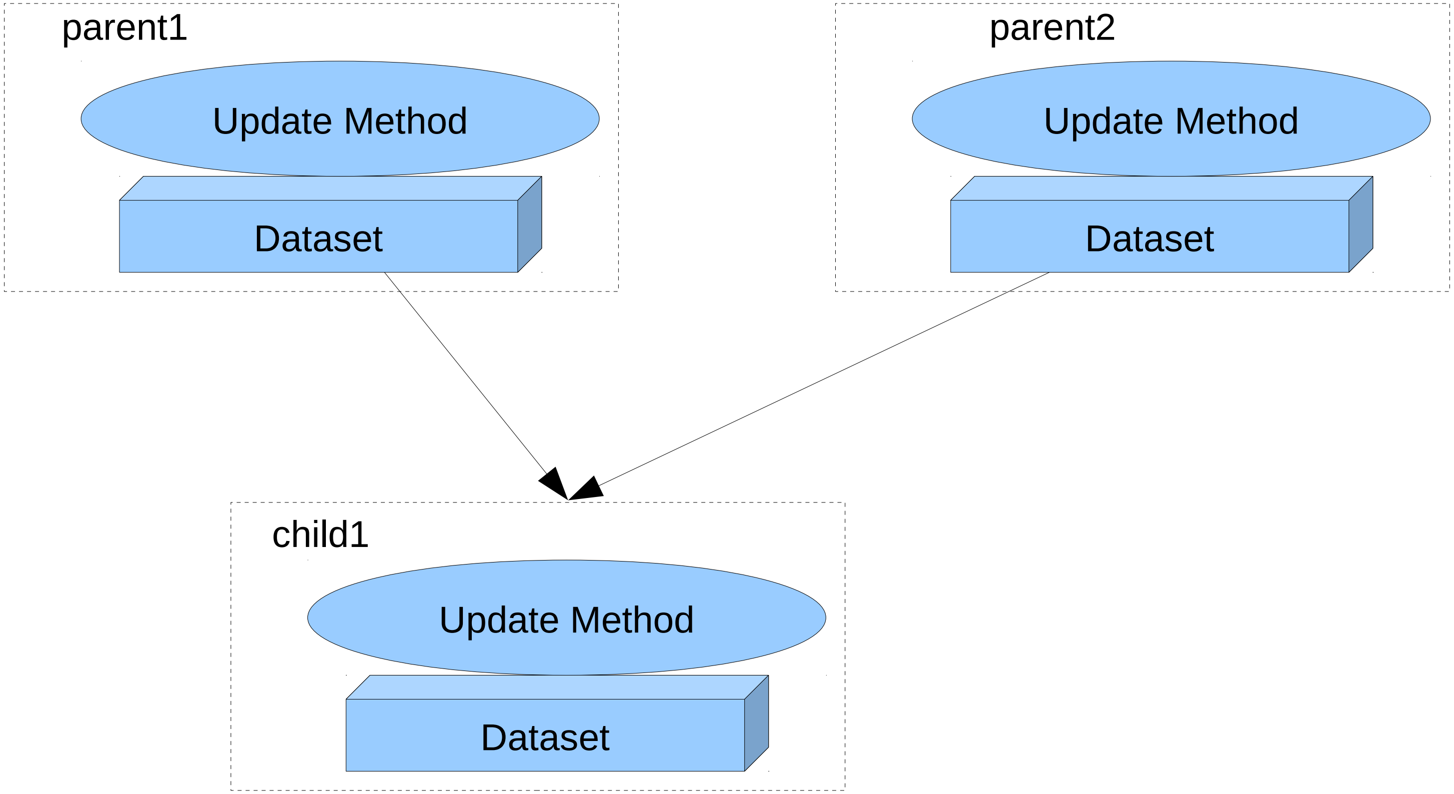
- **child1 <u>dependsOn</u> parent1 and parent2**
- **Inverse: parent1 <u>contributesTo</u> child1**
- **or maybe: parent1 isRequiredBy/supports/supplies/influences/affects child1**

Inside a pcache



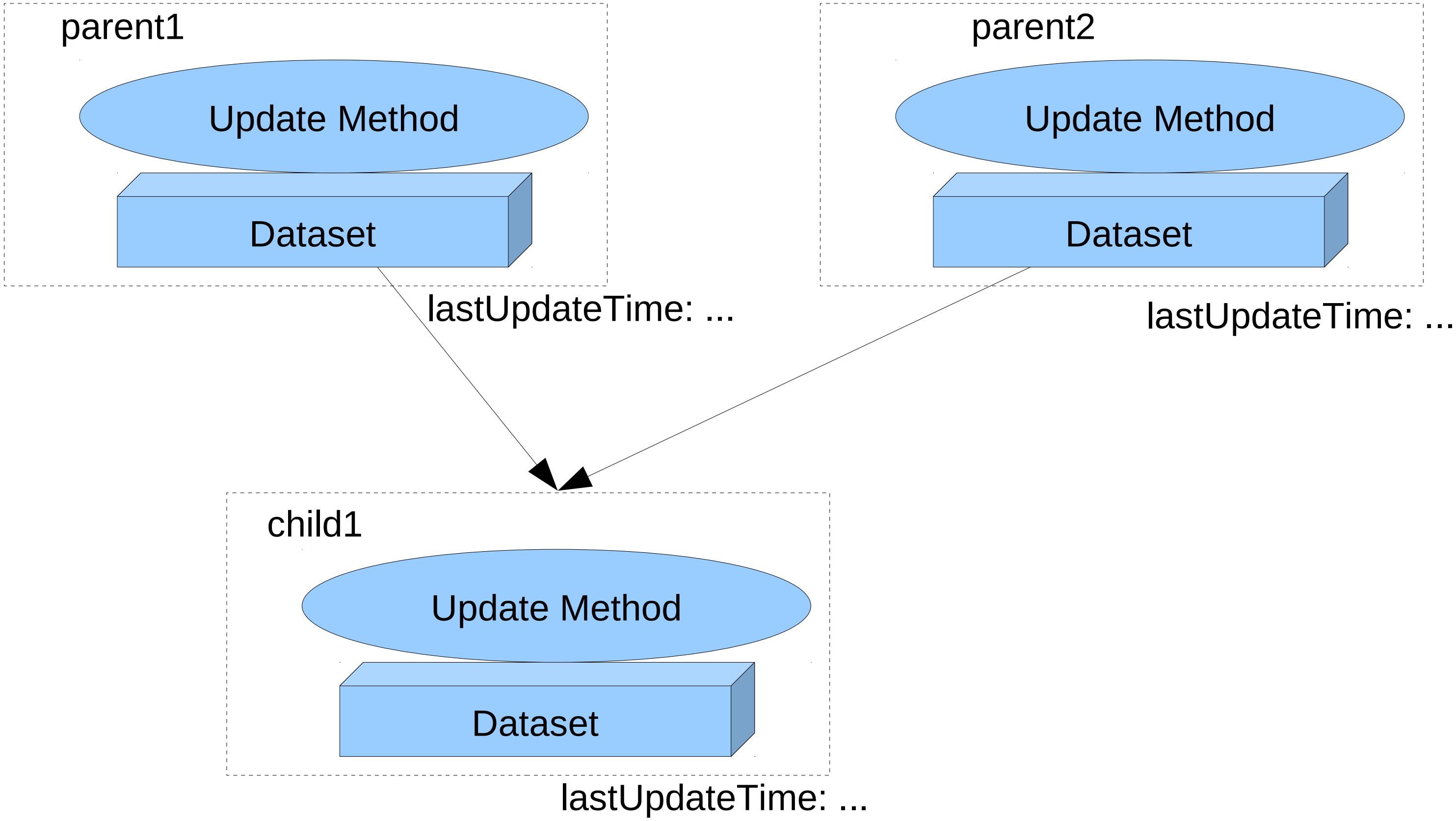
- **Each pcache has an update method, a dataset, an update policy and other metadata, e.g., provenance, updateTime**

Eager update



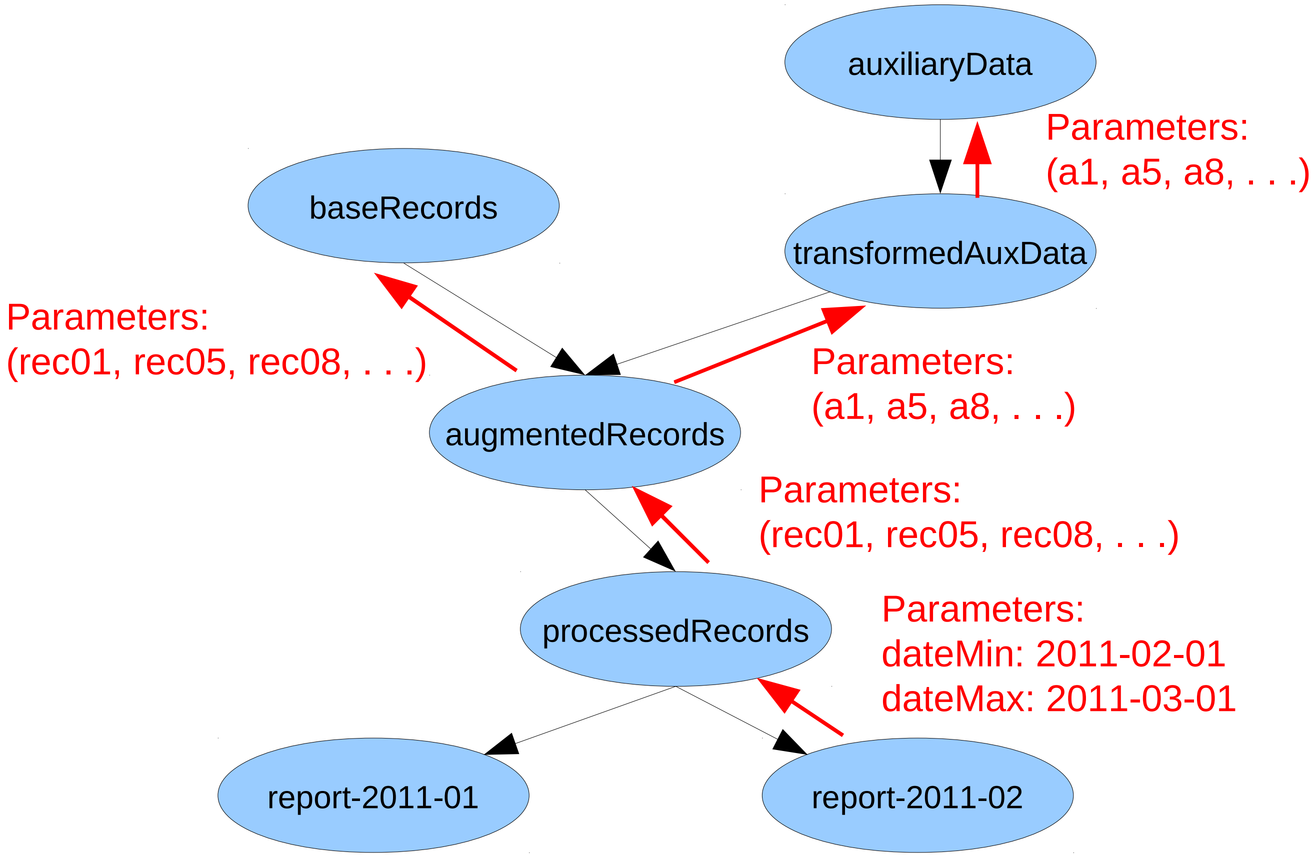
- **If parent1 or parent2 are updated, then run child1's update method, and so on recursively**
- **In general: if any parent is updated, update the child**

Lazy update



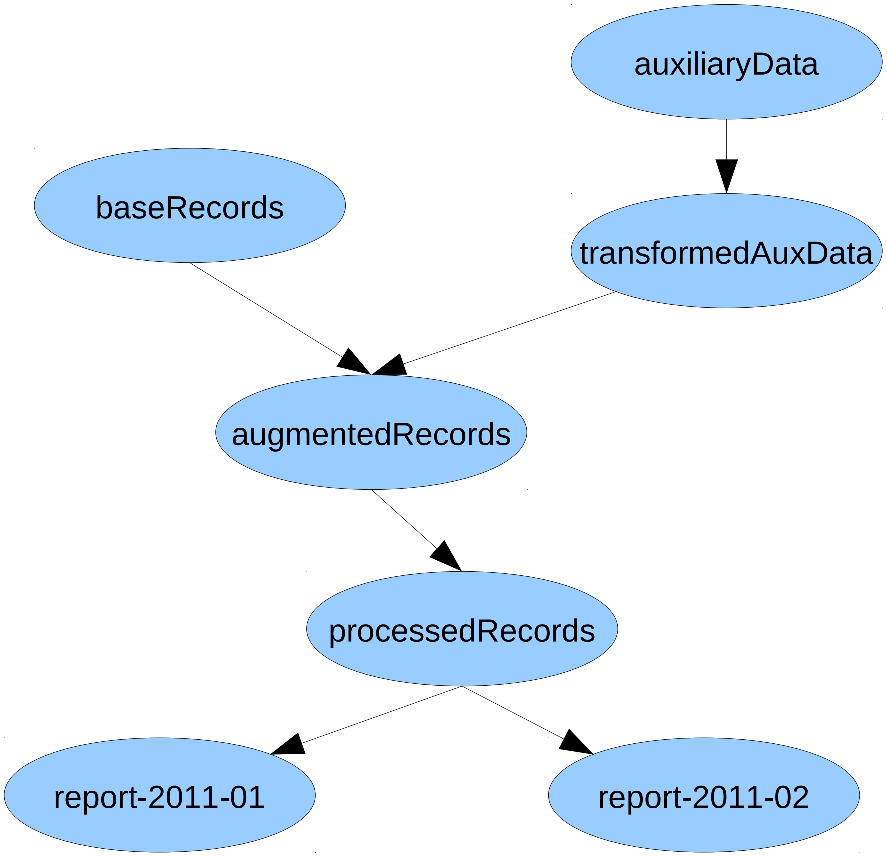
- **Each pcache has a lastUpdateTime**
- **If child1 is requested but out of date, then:**
  - **Recursively make sure parent1 and parent2 are up to date**
  - **Run child1's update method**

Example: Monthly report



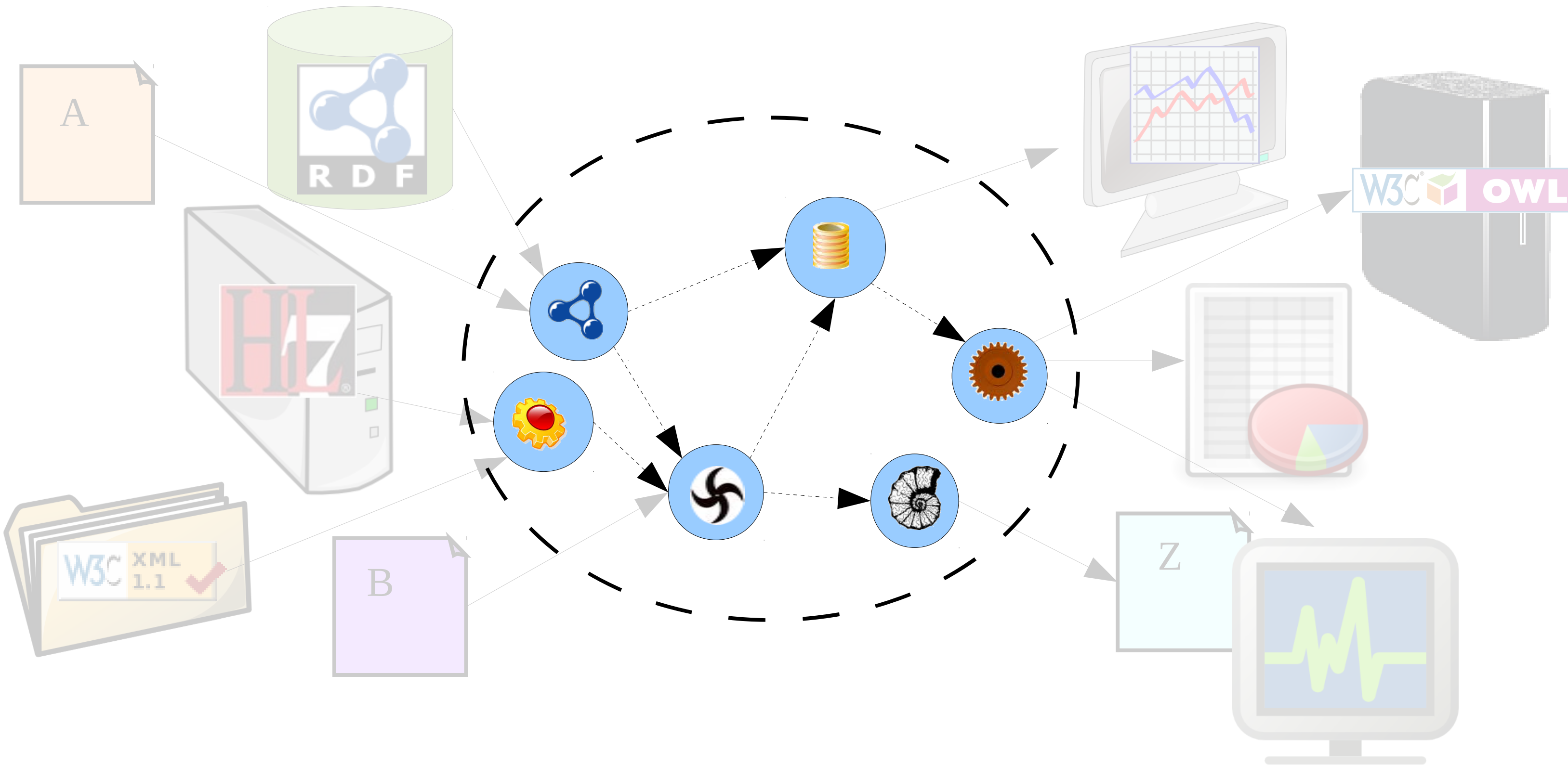
- **Downstream reports should auto update when baseRecords change**

Staleness



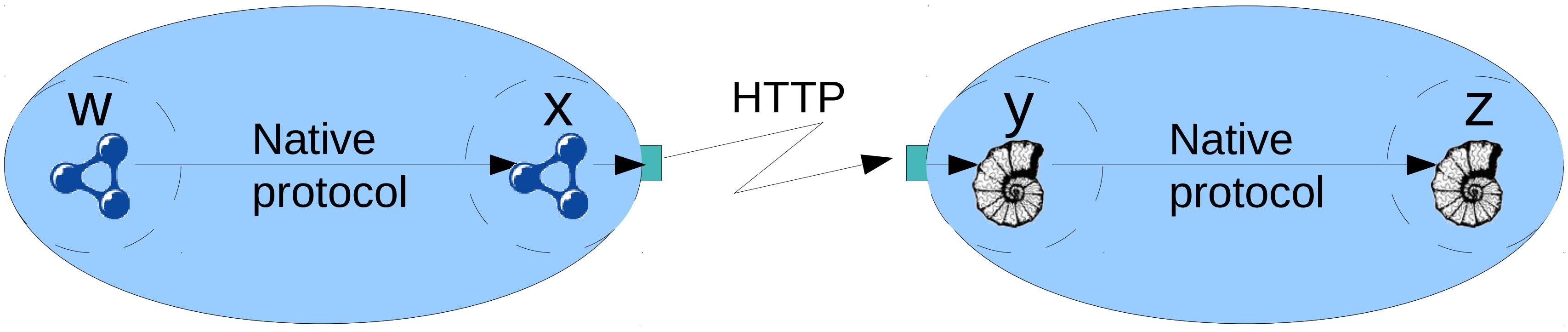
- **A node's output cache becomes <u>stale</u> if an input node changes**
  - **The node's update method must be invoked to refresh it**
- **E.g., when baseRecords is updated, augmentedRecords becomes stale**

Option 3: RDF data pipeline framework



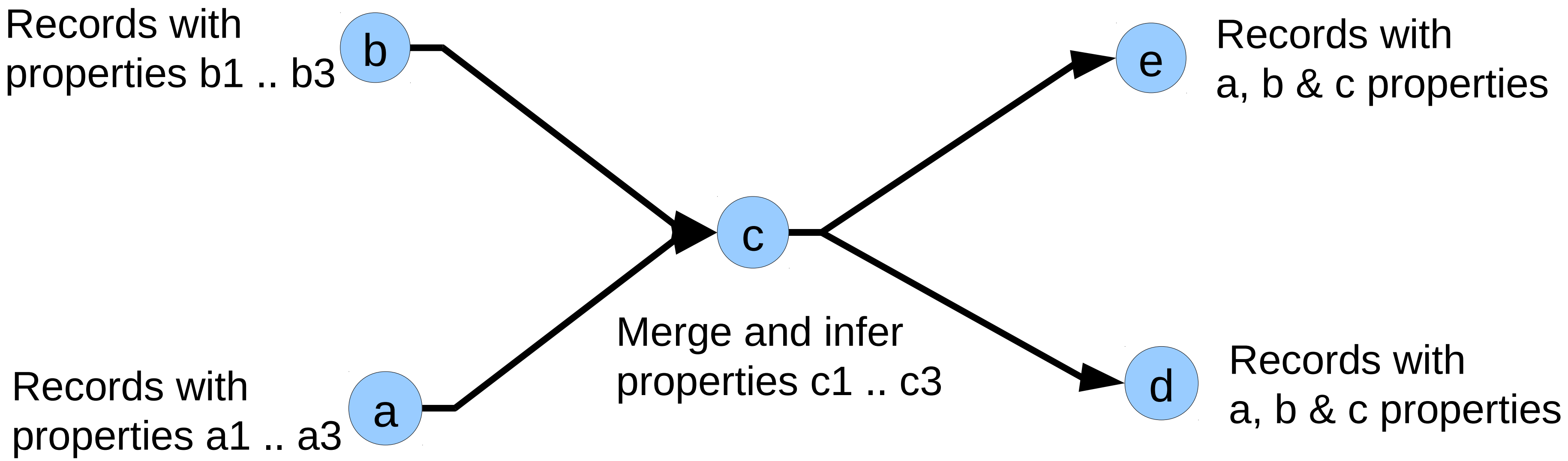
- **Uniform, distributed, data pipeline framework**
- **Custom code is hidden in standard wrappers**
- **Pros: Easy to build and maintain; Can leverage existing integration tools; Low risk - Can grow organically**
- **Cons: Can grow organically – No silver bullet**

Physical view - Optimized



- **But nodes that share an implementation environment communicate directly, using native protocol, e.g.:**
  - **One NamedGraphNode to another in the same RDF store**
  - **One TableNode to another in the same relational database**
  - **One Node to another on the same server**
- **Wrappers handle both native protocol and HTTP**

Example 1: Multiple nodes



- **Five nodes: a, b, c, d, e**
- **Node c merges and augments records from a & b**
- **Nodes d & e consume augmented records from c**

Data in node a

<s01> <a1> 111 .

<s01> <a2> 121 .

<s01> <a3> 131 .

<s02> <a1> 112 .

<s02> <a2> 122 .

<s02> <a3> 132 .

<s03> <a1> 113 .

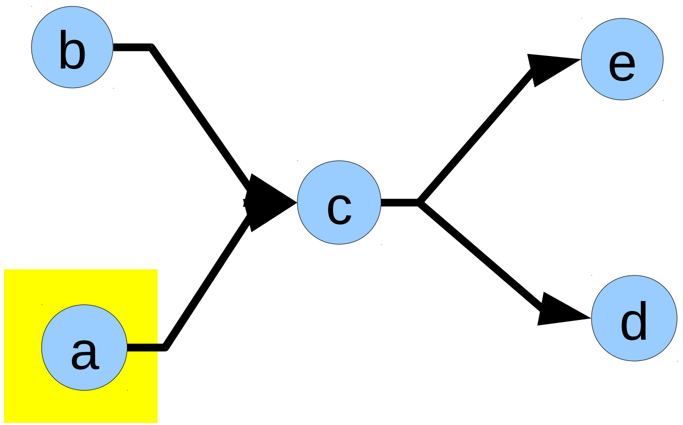
<s03> <a2> 123 .

<s03> <a3> 133 .

<s04> <a1> 114 .

. . .

<s09> <a3> 139 .



Data in node b

<s01> <b1> 211 .

<s01> <b2> 221 .

<s01> <b3> 231 .

<s02> <b1> 212 .

<s02> <b2> 222 .

<s02> <b3> 232 .

<s03> <b1> 213 .

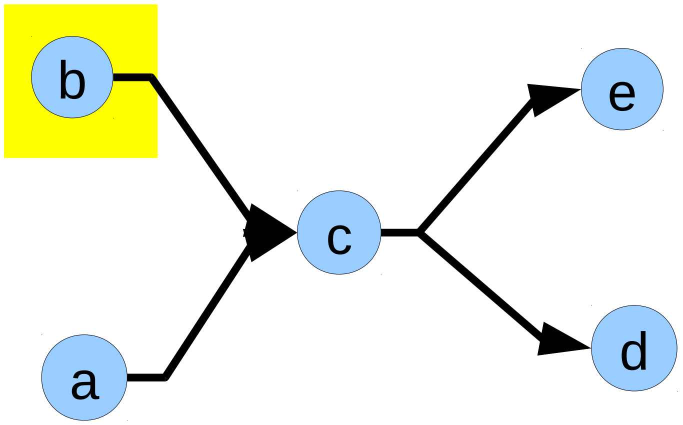
<s03> <b2> 223 .

<s03> <b3> 233 .

<s04> <b1> 214 .

. . .

<s09> <b3> 239 .



Data in node c

<s01> <a1> 111 .

<s01> <a2> 121 .

<s01> <a3> 131 .

<s01> <b1> 211 .

<s01> <b2> 221 .

<s01> <b3> 231 .

Merged triples

<s01> <c1> 111211 .

<s01> <c2> 121221 .

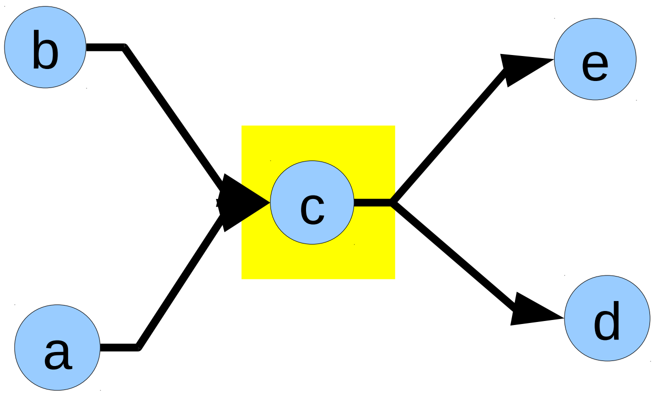
<s01> <c3> 131231 .

Inferred triples

<s02> <a1> 112 .

. . .

<s09> <c3> 139239 .



Data in nodes d&e: same as c

<s01> <a1> 111 .

<s01> <a2> 121 .

<s01> <a3> 131 .

<s01> <b1> 211 .

<s01> <b2> 221 .

<s01> <b3> 231 .

<s01> <c1> 111211 .

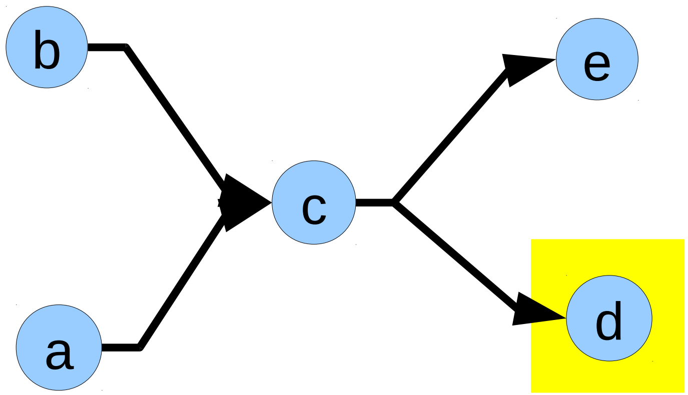
<s01> <c2> 121221 .

<s01> <c3> 131231 .

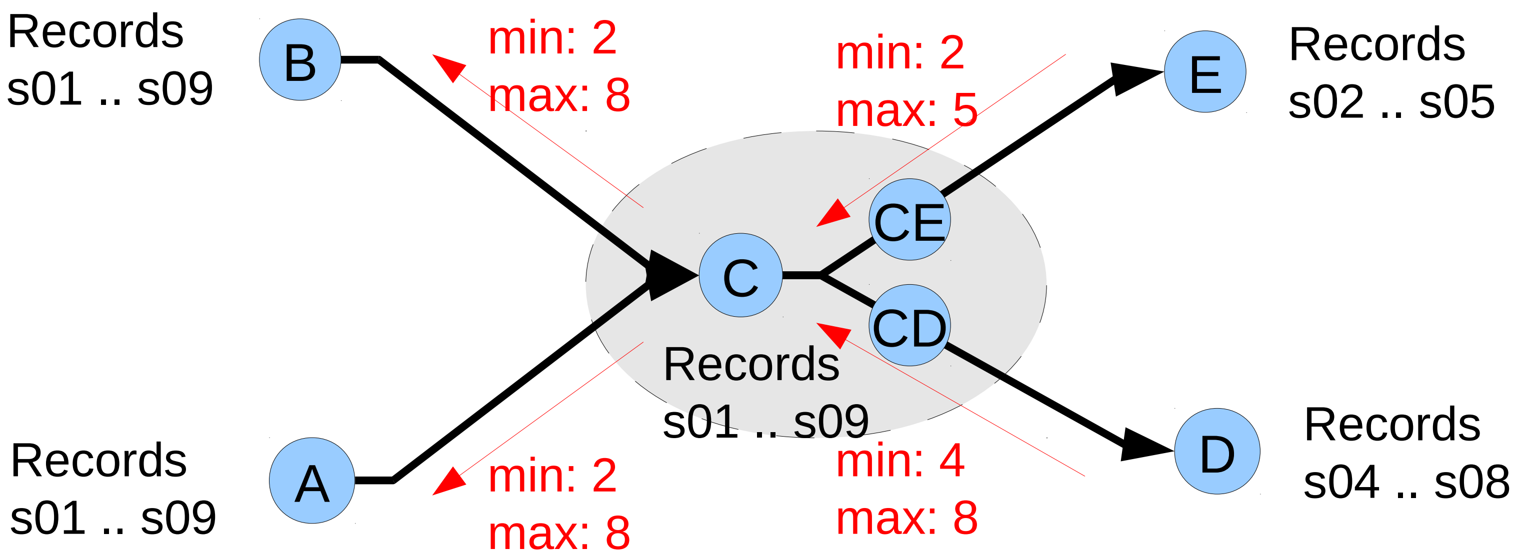
<s02> <a1> 112 .

. . .

<s09> <c3> 139239 .

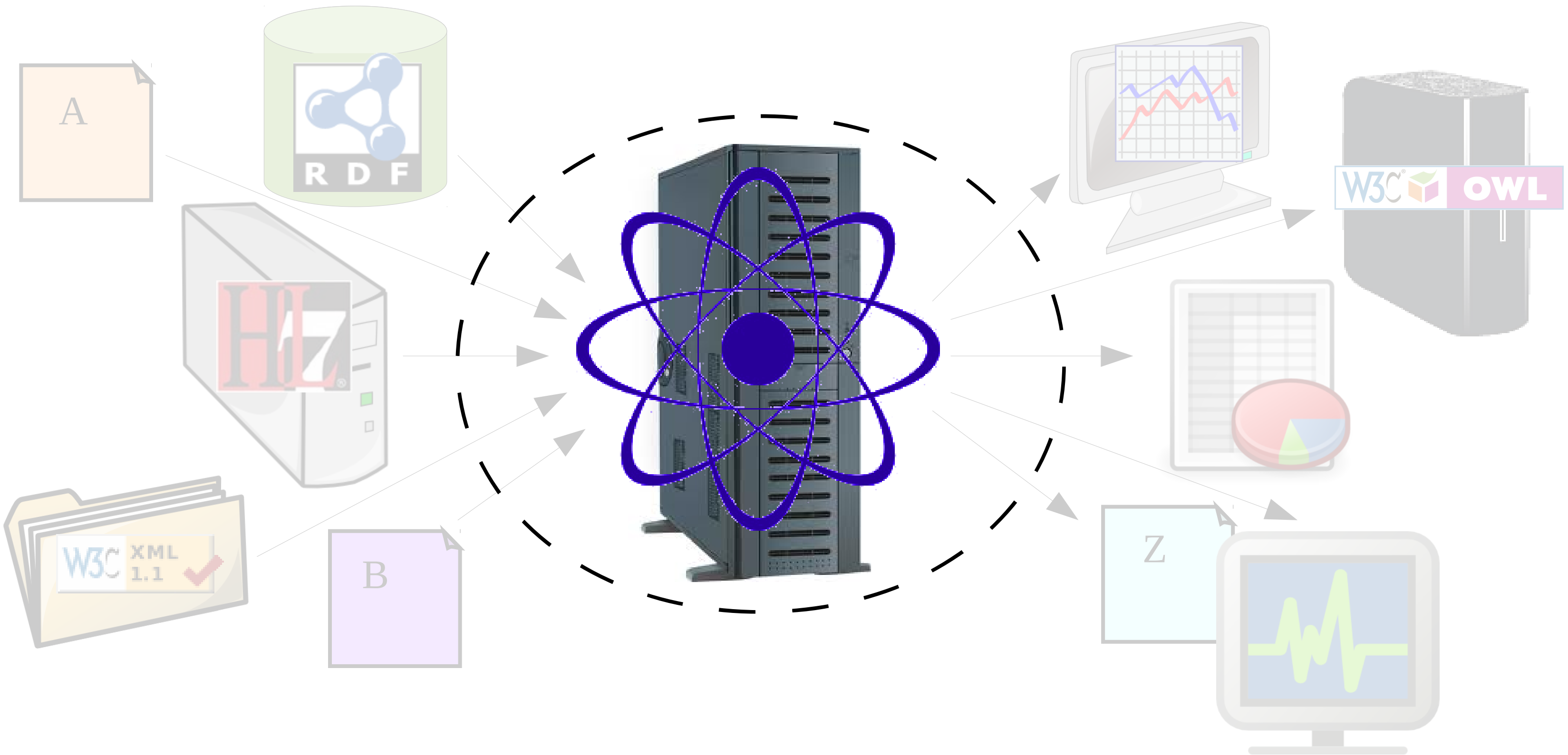


Example 2: Passing parameters upstream



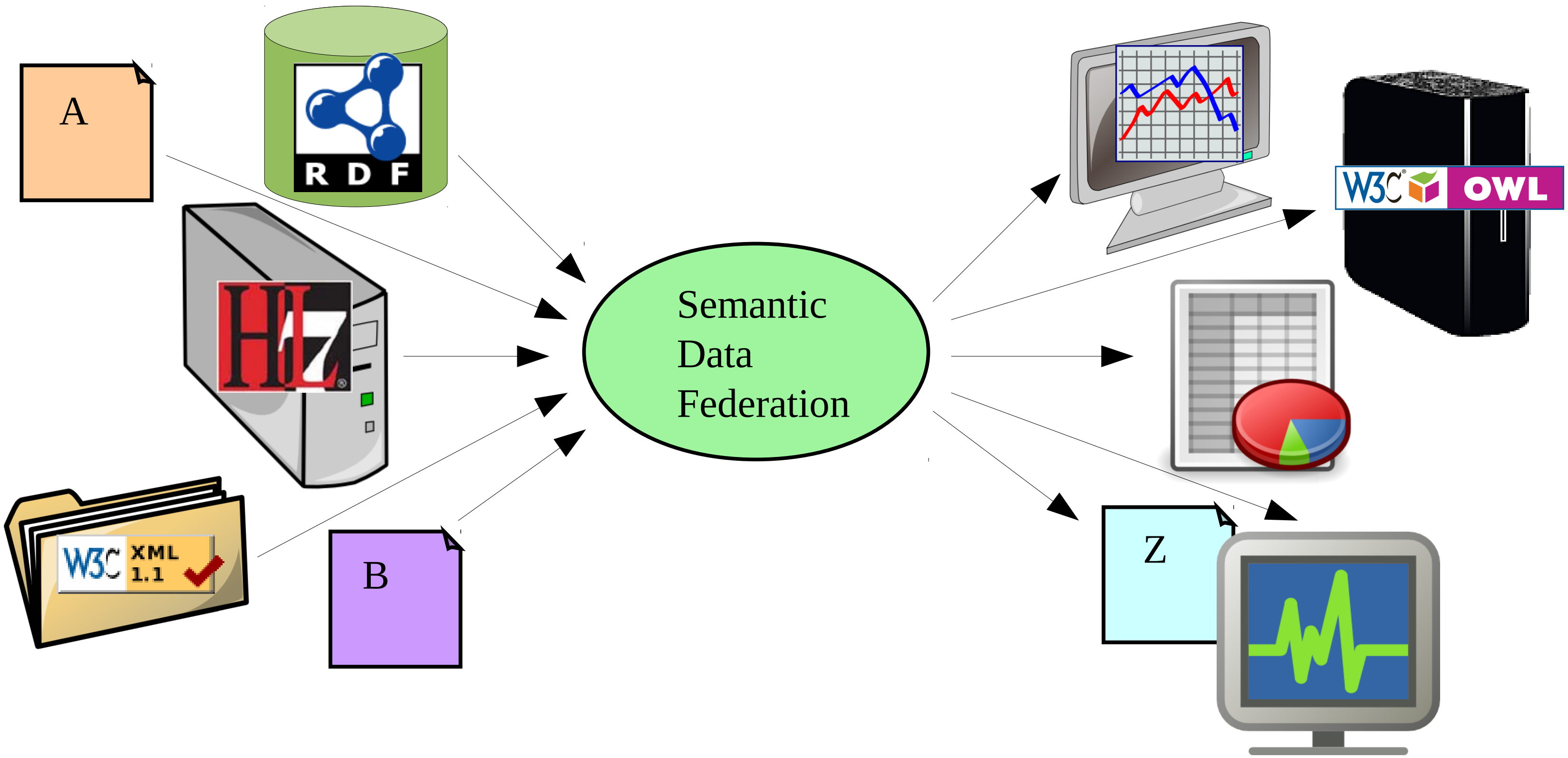
- **Node C may hold more records than D&E want**
- **Nodes D&E pass parameters upstream:**
  - **Min, max record numbers desired**
- **Node C supplies the <u>union</u> of what D&E requested**
- **Nodes D&E select the subsets they want: s04..s08 and s02..s05**
- **Node C, in turn, passes parameters to nodes A&B**

Option 1: Monolithic, big bang process



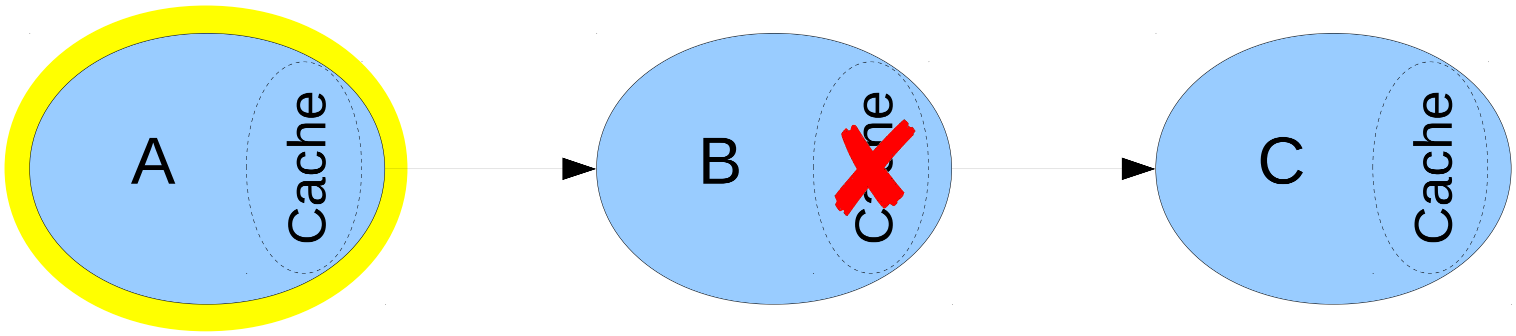
- **One monster process that handles all vocabularies, formats, data sources and applications**
- **Pros: Highest potential processing efficiency**
- **Cons: Huge complex ontology; Very risky to build (requirements evolve); Difficult to maintain**

Semantic Data Federation



- **Need to integrate and generate data from distributed, diverse:**
  - **vocabularies, formats and data sources**
- **Producing data for distributed, diverse:**
  - **vocabularies, formats and applications**
- **While each data consumer sees a single data source**

Staleness



- **A node's output cache becomes <u>stale</u> if any of its input nodes changes**
  - **E.g., B's cache becomes stale if A's cache changes**
- **Updater can refresh it**
- ***NOTE: Because different nodes may have different clocks (clock skew), the technique for determining staleness is slightly different from that used by Make***

labData

patientRecords

transformedLabData

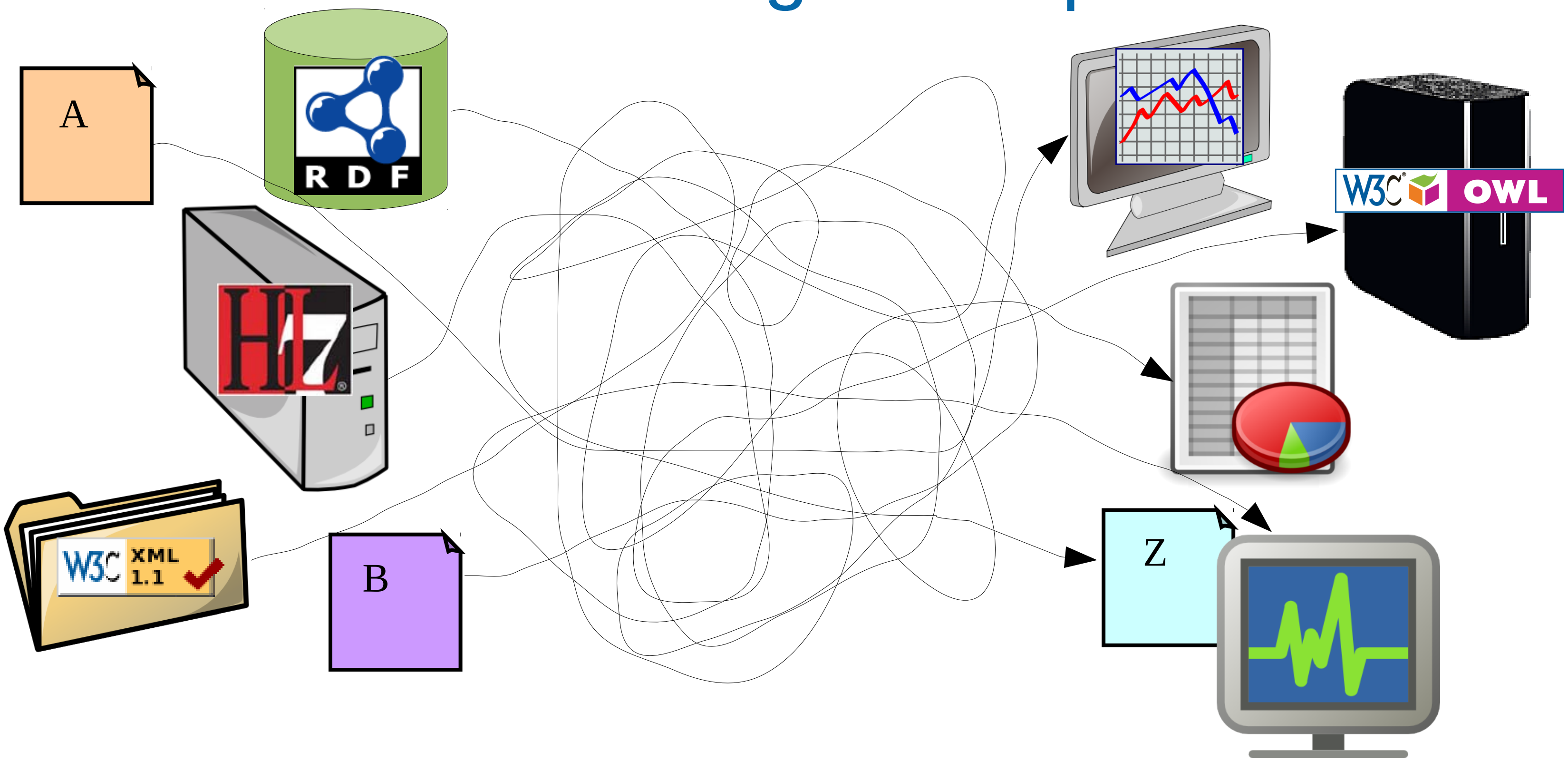
augmentedRecords

processedRecords

report-2011-01

report-2011-02

Data in a large enterprise



- **Many data sources and applications**
- **Each application wants the illusion of a single, integrated data source**

Summary of requirements

- **Easy to create nodes**
  - **Node may be written in any convenient language/environment**
  - **Any kind of data and storage – not only RDF**
  - **Node does not need to know how other nodes are implemented**
- **Easy to connect nodes**
  - **Add a few lines of RDF**
- **Parameters can be passed upstream**
- **Nodes are invoked automatically, based on dependencies, to update node data**
- **Flexible node data update policies**
  - **E.g., eager, lazy, periodic**
- **Efficient**
  - **Updates only what should be updated**
  - **Low node communication overhead**

Example pipeline definition (in N3)

```
@prefix p: <http://purl.org/pipeline/ont#> .
@prefix : <http://localhost/> .
:patientRecords a p:Node .
:labData a p:Node .
:transformedLabData a p:Node .
:augmentedRecords a p:Node .
        p:inputs ( :patientRecords :transformedLabData ) .
:processedRecords a p:Node .
        p:inputs ( :augmentedRecords ) .
:report-2011-jan a p:Node .
        p:inputs ( :processedRecords ) .
:report-2011-feb a p:Node .
        p:inputs ( :processedRecords ) .
```

Example pipeline definition (in N3)

1. @prefix p: <http://purl.org/pipeline/ont#> .
2. @prefix : <http://localhost/> .
3. :patientRecords a p:Node .
4. :labData a p:Node .
5. :transformedLabData a p:Node .
6. :augmentedRecords a p:JenaNode .
7. p:inputs (:patientRecords :transformedLabData) .
8. :processedRecords a p:JenaNode .
9. p:inputs (:augmentedRecords) .
10. :report-2011-jan a p:Node .
11. p:inputs (:processedRecords) .
12. :report-2011-feb a p:Node .
13. p:inputs (:processedRecords) .