Web Services for Time Granularity Reasoning

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TIME-ICTL 03 Invited Talk

Overview

- Time granularities
- Current approaches to time granularities
- Time granularity web services
- GSTP: the Granularity Simple Temporal Problem
- The GSTP web service

Time granularities

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- The set of granules can be used for temporal qualification of statements (e.g., *It has been raining for two weeks* or *Revenues in July 2003 are $500.000*) and for specifying temporal relationships (e.g., *The merchandise should reach its destination in 3 business days from the date of its order.*)

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- It is a powerful abstraction tool

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- From UC Berkeley: Students wanting to do a part-time internship during an *academic semester* must be enrolled at UC Berkeley for the semester of their internship
- From Morgan Stanley Mutual Fund Prospects:
  By *business day* we mean any day in which Banks are open in Luxemburg, New York and Tokyo depending on the specific case.

Time granularities can have complex definitions

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From NYSE web site:
"If an observable holiday occurs on a Sunday it is observed on Monday, If on Saturday, it is observed on Friday. The exception to this rule is New Years. If it falls on a Saturday, the Market will be open on Friday, as the NYSE is ALWAYS open on the last trading day of the year."

Time granularity research issues

- Modeling time granularities
- Granule conversions
- Conversion of information in terms of different granularities
- Time granularity constraint reasoning

Current approaches to time granularities

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  Goal: a full-fledged logic to reason about multi-granularity temporally qualified statements.

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  Goal: a full-fledged logic to reason about multi-granularity temporally qualified statements.

- *The set-theoretic approach.*
  Goal: a mathematical model for arbitrary granularities and an associated algebra to manipulate them, plus a set of domain-specific reasoning tools.

The multilayered logic approach

- Extensions of topological temporal logic
- Temporal universe consisting of a (possibly infinite) set of inter-related differently-grained temporal domains
- Logical tools are provided to qualify temporal statements with respect to the temporal universe and to switch temporal statements across temporal domains.
- Main application: real time systems specification and verification

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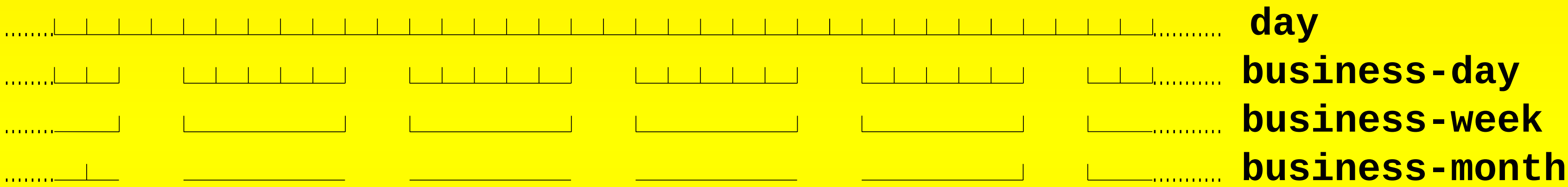
Angelo Montanari. *Metric and layered temporal logic for time granularity.* PhD thesis, University of Amsterdam. ILLC DIssertation Series 1996-02.

Time granularities in the set-theoretic approach

A *granularity* is a mapping G from the positive integers to $2^{\mathcal{T}}$ (i.e., all subsets of a lineraly ordered temporal domain) such that for all positive integers i and j with $i < j$, the following two conditions are satisfied:

- $G(i) \neq \emptyset$ and $G(j) \neq \emptyset$ imply that each element in $G(i)$ precedes all elements in $G(j)$, and
- $G(i) = \emptyset$ implies $G(j) = \emptyset$.

Examples of time granularities



Example of granules:

day(1) = 0001/01/01

day(731405) = 2003/07/09

The set theoretic approach

- Many granularity relationships formally defined (groups-into, finer-than, periodically groups-into, sub-granularity, shifting equivalent, ...)
- Different time granularity systems have been investigated identifying systems with nice properties (e.g., lattices).

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C. Bettini, S. Jajodia, and X. Wang. *Time Granularities in Databases, Temporal Reasoning, and Data Mining*. Springer, 2000

System representations of time granularities

Assume `hour` is the bottom granularity with `hour`(1) mapped to the instants corresponding to 2001/1/1:01, then:

- `monday` can be represented in terms of `hour` by:
  Period $P = 168$;
  Description of one of the periods: $\{[1, 24]\}$
  Bounds: none.

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  Period $P = 168$;
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- `business-day-until-2003` can be represented by:
  Period $P = 168$;
  Description of one of the periods:
  {[1,24][25,48][49,72][73,96][97,120]}
  Bounds: Up=775 (number of business days from 2001 to 2003).

Primitive granule conversion operations

If $\mathtt{day}(1)$ is January 1st 2001, then:

- $\lceil 33 \rceil^{\mathtt{month}}_{\mathtt{day}} = 2$ since Feb. 2nd 2001, represented in the system as $\mathtt{day}(33)$, is contained in Feb. 2001, the second month, represented in the system as $\mathtt{month}(2)$.

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- $\lfloor 2 \rfloor^{\mathtt{b\text{-}month}}_{\mathtt{day}} = \{[32, 33][36, 40][43, 47][50, 54][57, 59]\}$ since the second business month includes only the days of February 2001 which are not Saturday nor Sunday.

Investigated applications

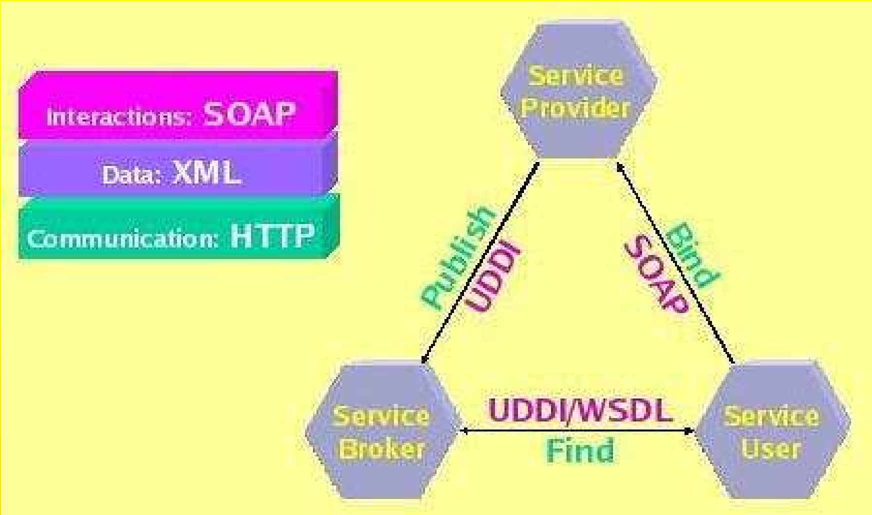
- Databases: temporal query processing and temporal database interoperability, temporal database design, multiple granularity integrity constraint checking;
- Data mining: discovering frequent temporal patterns, discovering temporal relationships;
- Artificial Intelligence: multi-granularity constraint processing, scheduling in inter-organizational workflows.

The set-theoretic model and its basic services were a common basis in the proposed solutions (but different techniques were applied).

Time granularity web services

Web services

- A technology to enable distributed Web applications
- Based on: HTTP, SOAP, WSDL, UDDI
- Language and platform independent



Why time granularity web services?

- Managing distributed repositories of XML time granularity specifications
- Offering processing services to web applications. For example:
  - Specification of new granularities (using common algebra operators)
  - Search for equivalent specifications (name clash problem)
  - Conversion of granules
  - Constraint processing
  - ...

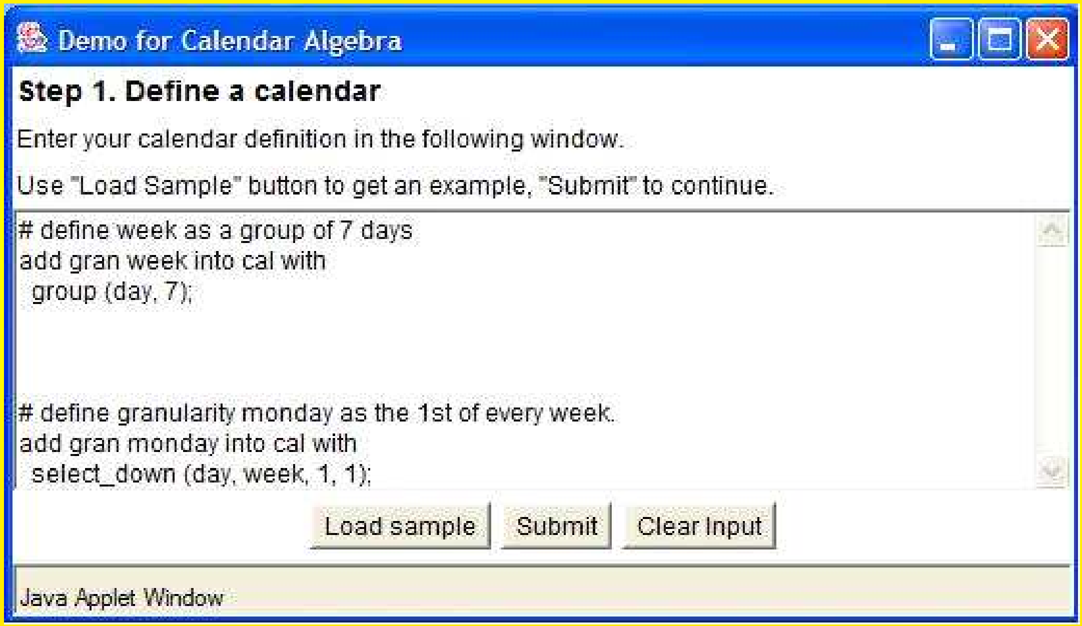
Which applications

Essentially all applications requiring multi-granularity time-management.

Focus on some of them:

- Inter-organizational workflows
- Personal (or group) Information Management (e.g., different views in Outlook-like apps, appointment scheduling)
- Medical applications (e.g., monitoring)
- ...

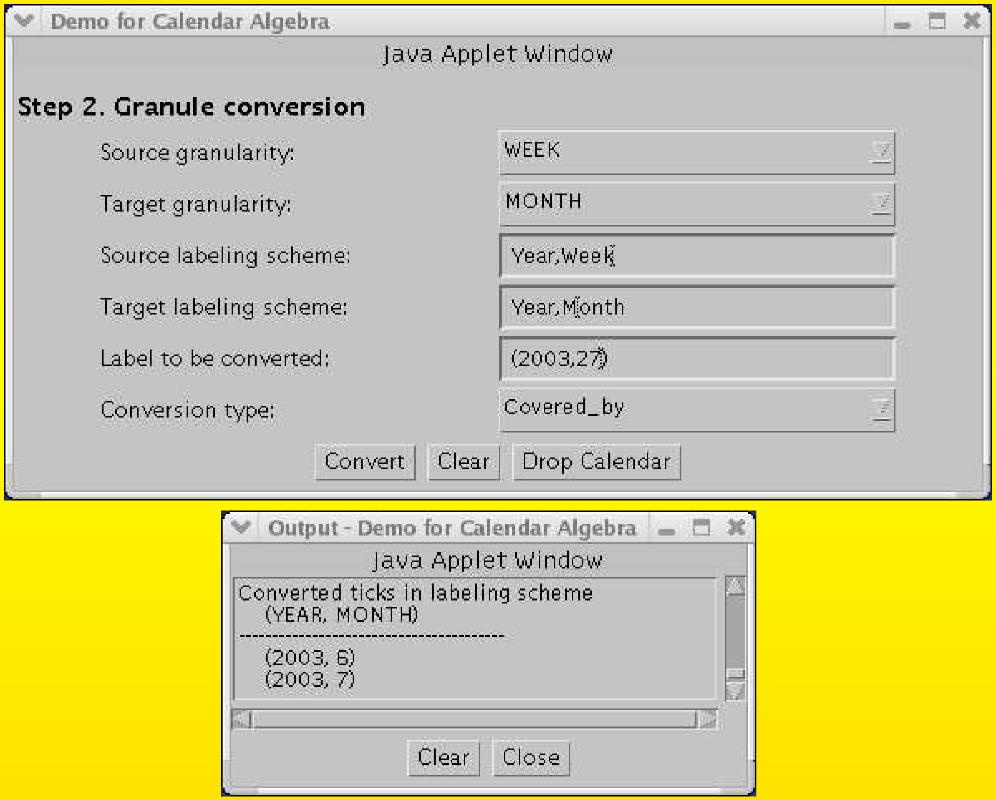
Granularity specification web services



Screenshot of a client-server application developed at GMU.

Granule conversion web services

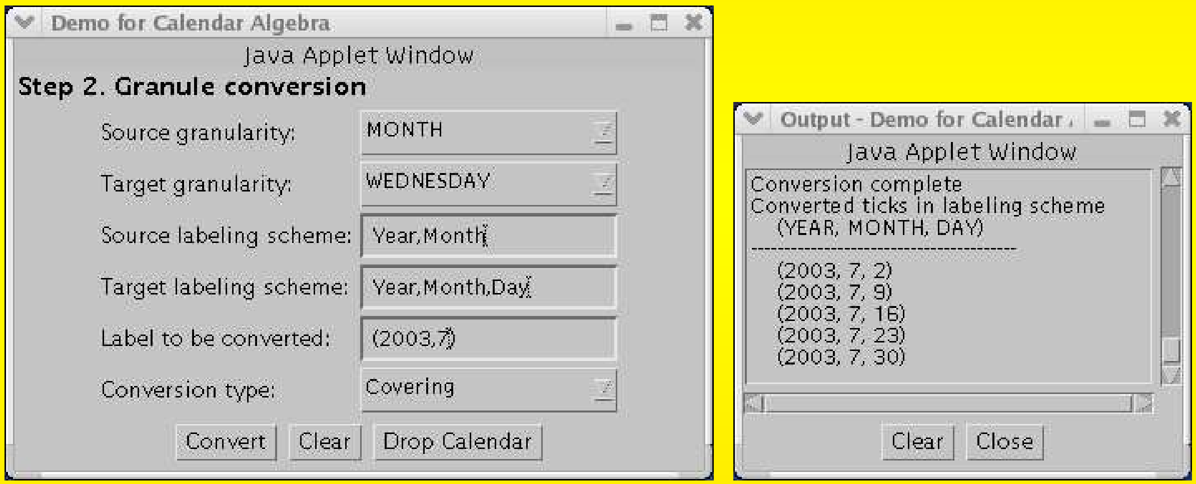
Find the month that contains the 27th week in 2003.



Screenshot of a client-server application developed at GMU.

Granule conversion web services (2)

Find all the Wednesdays in July 2003.

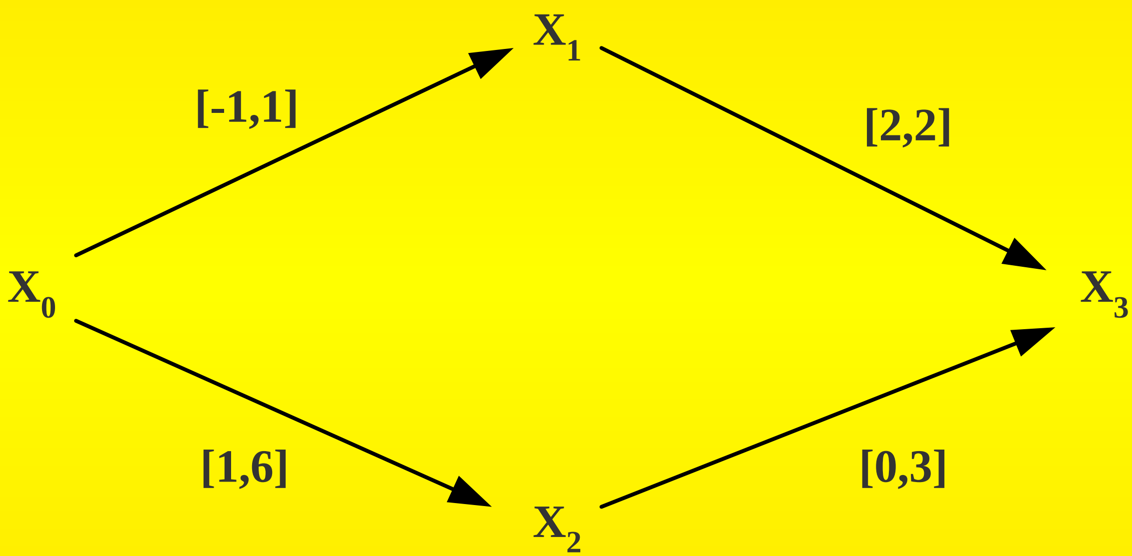


P. Ning, X. Wang, S. Jajodia. An Algebraic Representation of Calendars. *Annals of Mathematics and Artificial Intelligence* 36(1-2): 5-38, 2002.

GSTP: the Granularity Simple Temporal Problem

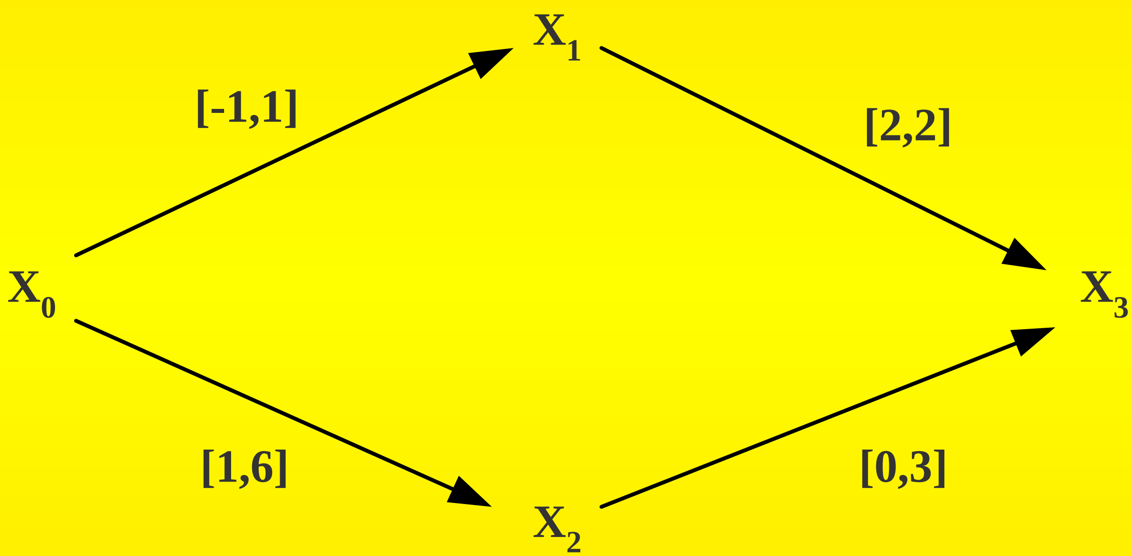
(The theory underlying a constraint processing web service)

Temporal constraint networks



A Simple Temporal Problem (STP).

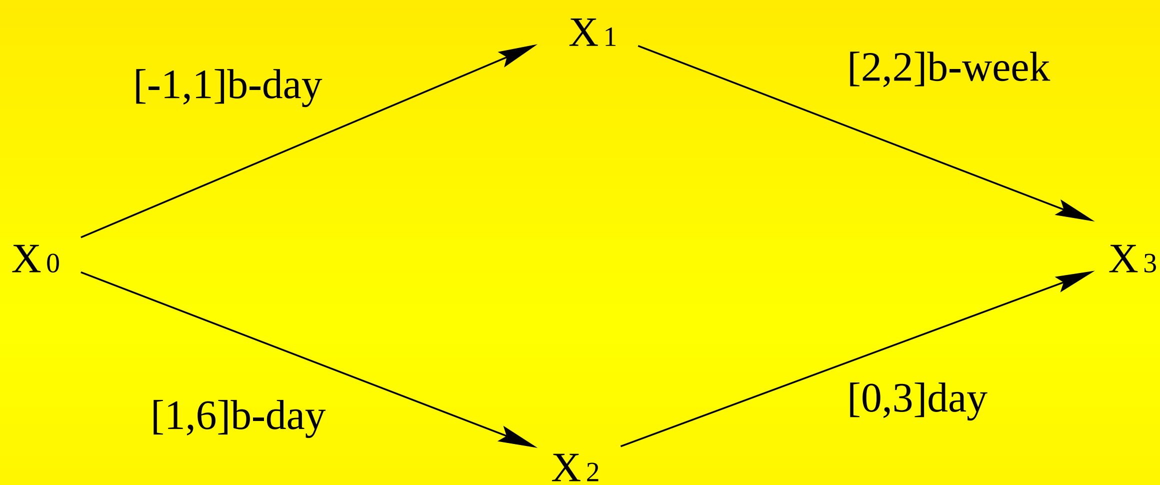
Temporal constraint networks



A Simple Temporal Problem (STP).

Main tasks: consistency, constraint refinement, solution

Temporal constraint networks with granularities



Variables take values in $\mathbb{Z}^+$.

(x_0, x_1) satisfies $[-1, 1]\texttt{bday}$ iff
(1) $\lceil x_0 \rceil^{\texttt{bday}}$ and $\lceil x_1 \rceil^{\texttt{bday}}$ are both defined, and
(2) $-1 \leq (\lceil x_1 \rceil^{\texttt{bday}} - \lceil x_0 \rceil^{\texttt{bday}}) \leq 1$

The intuitive approach

Convert the network constraints in terms of a single granularity, and apply known (polynomial time) algorithms for STP.

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Convert the network constraints in terms of a single granularity, and apply known (polynomial time) algorithms for STP.

Unfortunately, there is no straightforward reduction. Consistency is NP-hard in terms of the involved granularities [Bettini et al. TIME96 and AMAI98].

An approximate algorithm: Conversion+PC

- Compute the tightest implied constraints in terms of each granularity, generating a set of networks
- Process each network with known algorithms
- Rejoin the networks and repeat from step 1 until a fixpoint is reached

The conversion problem

$[1, 1]\,\texttt{bday} \longrightarrow [?, ?]\,\texttt{day}$

$[1, 1]\,\texttt{bday} \longrightarrow [?, ?]\,\texttt{hour}$

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Why not $[1,1]\,\texttt{day}$?

What about one event on Friday and the other on Monday?

The conversion problem

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$[1, 1]\,\texttt{bday} \rightarrow [?, ?]\,\texttt{hour}$

Why not $[1, 1]\,\texttt{day}$?
What about one event on Friday and the other on Monday?

Why not $[1, 100]\,\texttt{hour}$?
It is *implied* but a tighter implied constraint exists: $[1, 95]\,\texttt{hour}$.

The conversion problem (2)

$$[\mathbf{1},\mathbf{1}]\,\texttt{bday} \quad \rightarrow \quad [\mathbf{1},\mathbf{95}]\,\texttt{hour}$$

Can $[1, 95]\,\texttt{hour}$ *substitute* $[1, 1]\,\texttt{bday}$?
(2003/7/9:14,2003/7/12:14) satisfies $[1, 95]\,\texttt{hour}$
but violates $[1, 1]\,\texttt{bday}$

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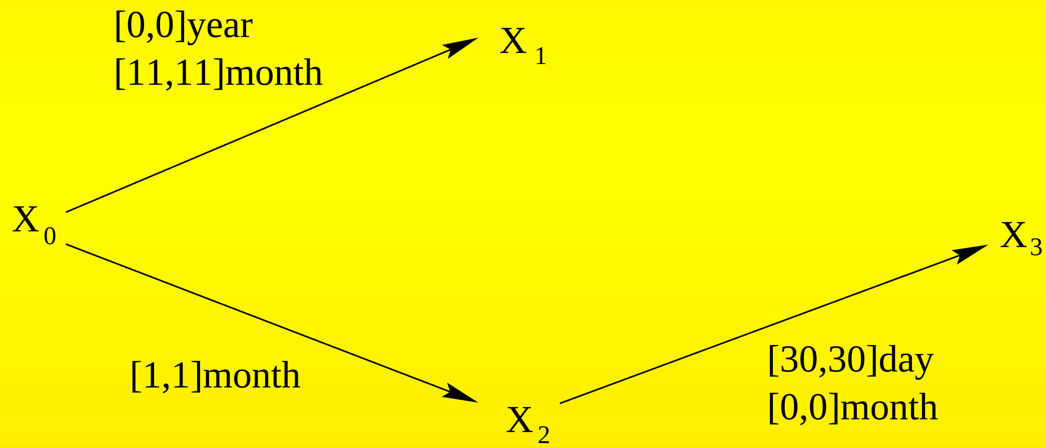
Converting constraints is tricky!
New algorithms presented in [Bettini, Ruffini AAAI-WS02 and JUCS].

Why incomplete?

Consider this example with only “standard” granularities:



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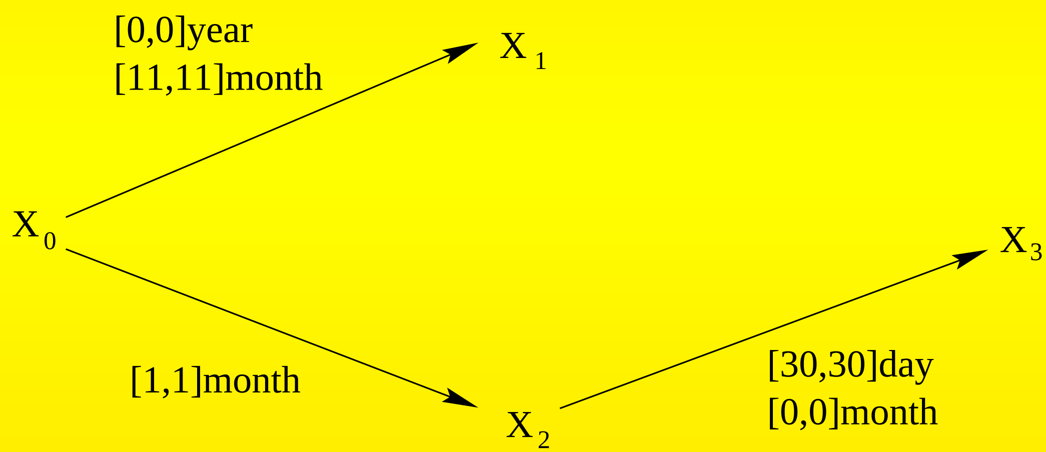
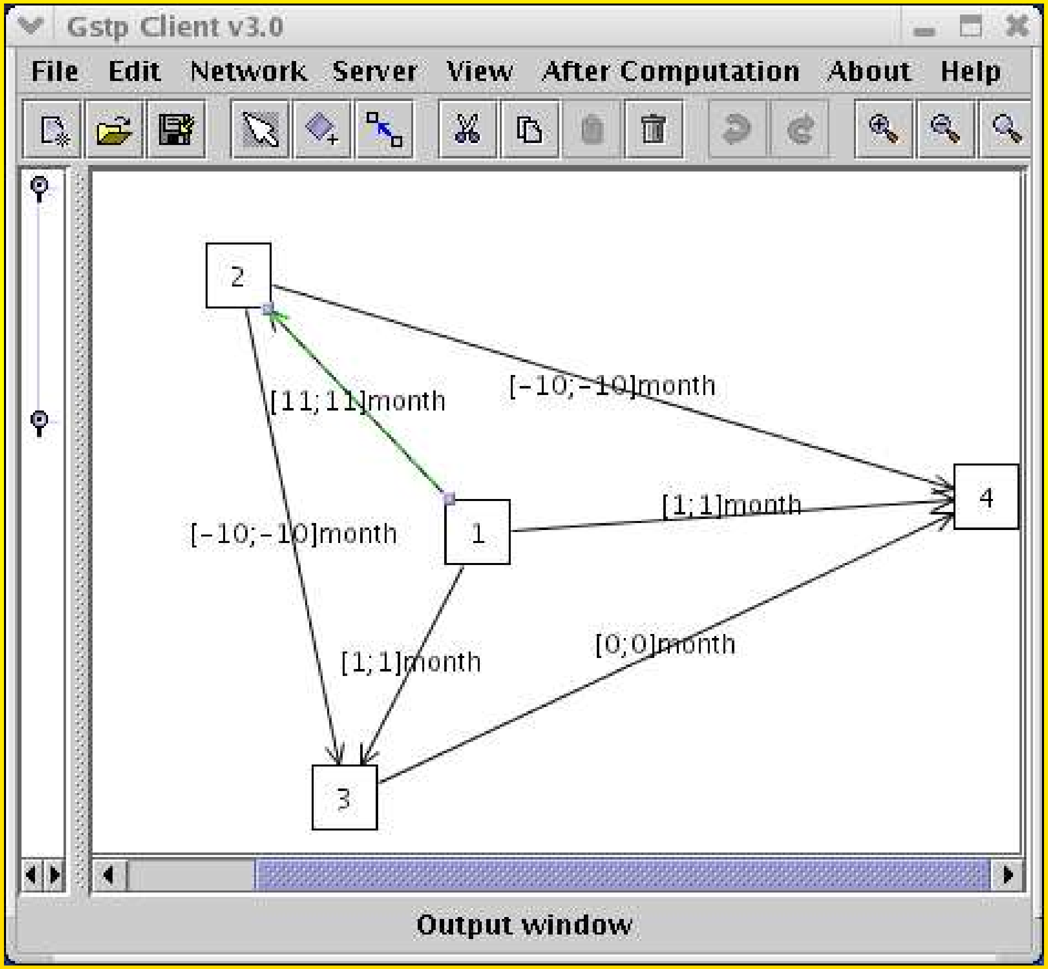
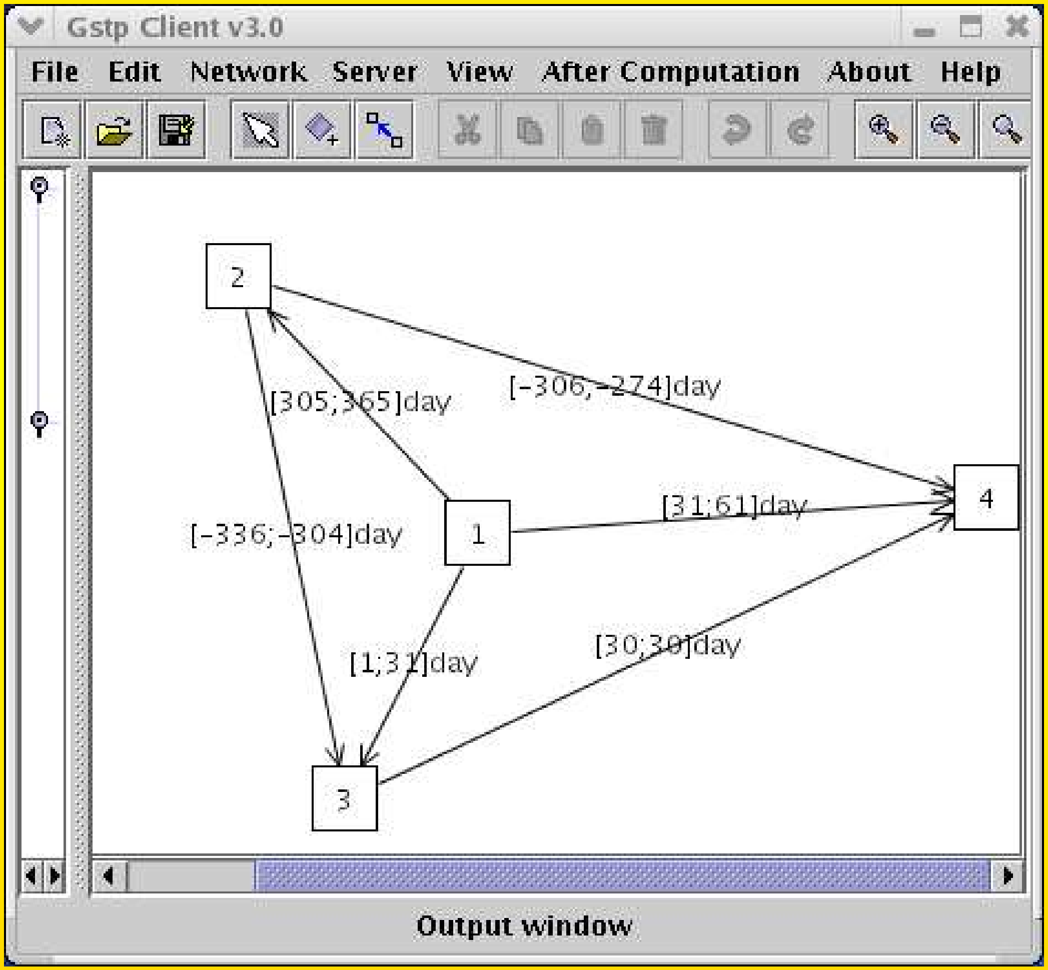


Intuition: We have to take into account the domain of involved variables

A minimal network in terms of `month`



A minimal network in terms of day



A sound and complete algorithm: AC-G

$Q := \{(X_i, X_j) \mid (X_i, X_j) \in A\}$
while $Q \neq \emptyset$ **do**
1. select and delete an arc (X_l, X_k) from Q
2. **if** $Dom(X_l) \neq^{MAX} Dom(X_l) \cap (Dom(X_k) \uplus \Gamma(X_k, X_l))$ **then**
   2.1. $Q := Q \cup \{(X_i, X_l) \mid (X_i, X_l) \in A,\ i \neq k\}$
   2.2. $Dom(X_l) := Dom(X_l) \cap (Dom(X_k) \uplus \Gamma(X_k, X_l))$
3. **if** $Dom(X_l) =^{MAX} \emptyset$ **then** $Q := \emptyset$; $Dom(X_l) := \emptyset$

end while

[Bettini et al. CP97 and AIJ02]. Key theorem: a solution exists iff there is one with all values lower than a network-dependent constant MAX.

The GSTP algorithm

Repeat

1. Conversion+PC
2. AC-G
3. RefineEdgesFromNodes()

Until no change is observed

Return Inconsistent **or** NewNetwork+solution

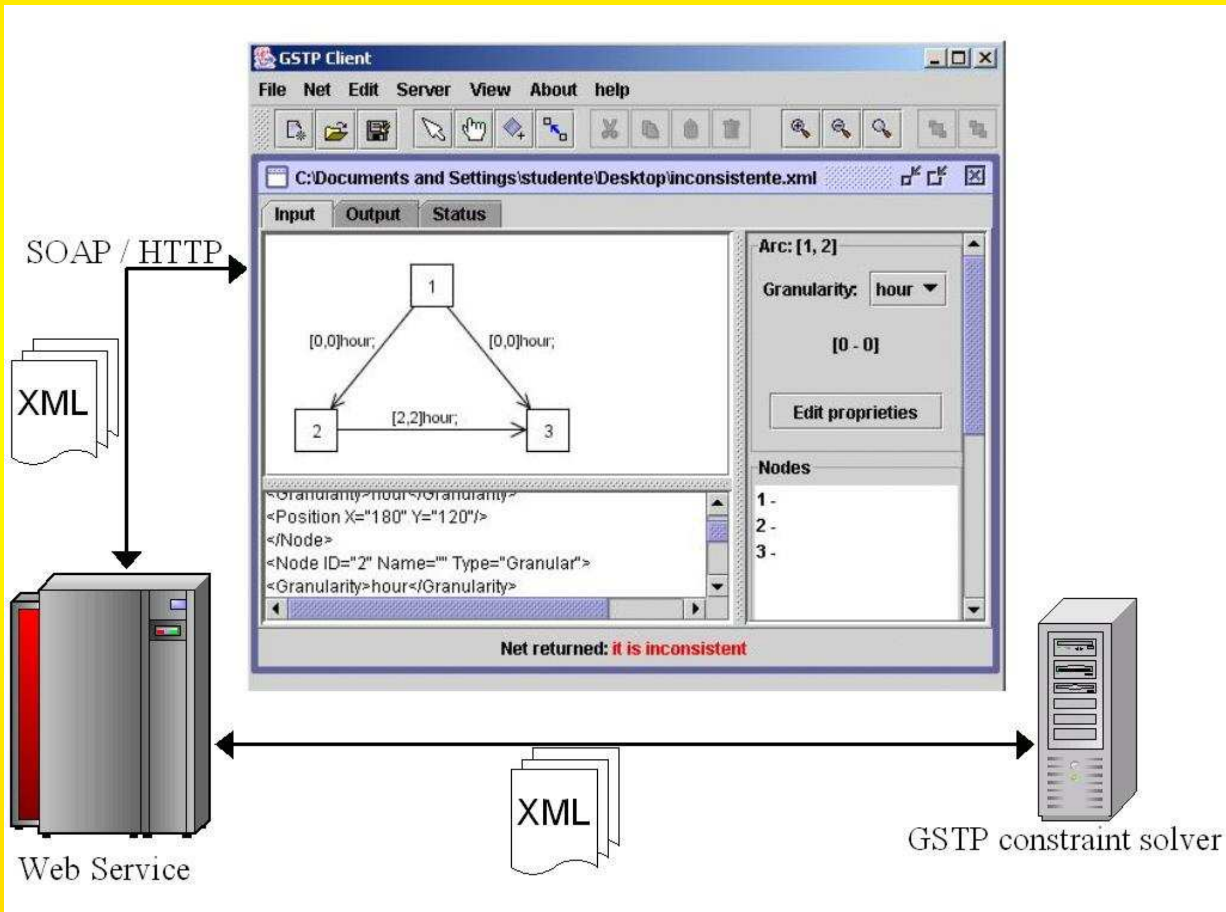
The GSTP web service

- Definition of an XML schema for constraint networks

```
...
<xsd:complexType name = "ArcType">
 <xsd:sequence>
  <xsd:element name="constraint" type="ConstrType" minOccurs="1"/>
 </xsd:sequence>
 <xsd:attribute name="sourceNodeID" use="required" type= .../>
 <xsd:attribute name="targetNodeID" use="required" type= .../>
</xsd:complexType>
...
```

- WSDL service description made available to external applications. (Services: consistency, refinement, solution, ...)

The GSTP web service architecture



References

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- C. Bettini, X. Wang, S. Jajodia, Solving Multi-Granularity Constraint Networks, *Artificial Intelligence*, 140(1-2):107–152, 2002.
- C. Bettini, S. Jajodia, X. Wang, *Time Granularities in Databases, Temporal Reasoning, and Data Mining*. Springer, 2000.

Thank you for your attention

`http://webmind.dico.unimi.it/gstp`