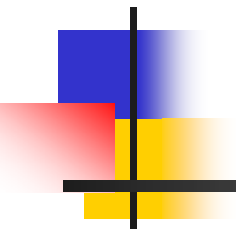
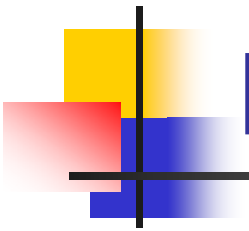


Constraint-based Information Integration

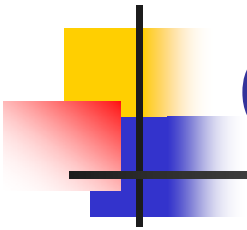
Craig Knoblock
University of Southern California

Thanks to Jose Luis for some of these slides

Constraint Satisfaction and Propagation for Integration



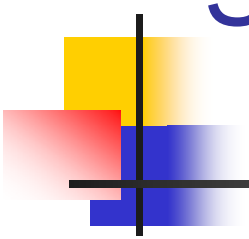
- Integrating data from multiple sources often involves reasoning about the information
- Constraints provide a approach to expressing relationships and filtering data



Outline

- Part I
  - Constraint satisfaction in SmartClients
  - Constraint propagation in Heracles
- Part II (Dr. Jose Luis Ambite)
  - Building your own applications in Heracles

SmartClients [Torrens et al, 2002]

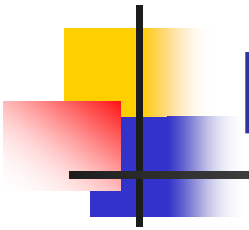


- Cast an integration problem as a Constraint Satisfaction Problem (CSP)
- Given a request, the server retrieves the required data and sends the data and the CSP to the client
- Client solves the CSP locally
  - Large complex problem transmitted in small amount of space
  - Provides fine-grained user interaction with the data

Example Problem

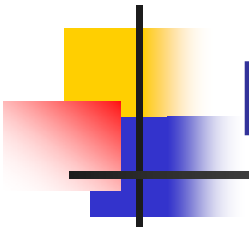
- I live in Bern, Switzerland, and would like to visit colleagues in Priceton and London. I would like to spend at least two days in each place, and will need to travel in the first two weeks of February.
  - 1st leg from Bern to Priceton: flights from ZRH/BSL/GVA to JFK/EWR/PHL on the dates from 1st to 10th February
  - 2nd leg from Princeton to London: flights from JFK/EWR/PHL to LGW/LHR/LCY on the dates from 4th to 12th February, and
  - 3rd leg from London to Bern: flights from LGW/LHR/LCY to ZRH/BSL/GVA on the dates from 6th to 14th February

Constraint Satisfaction Problem



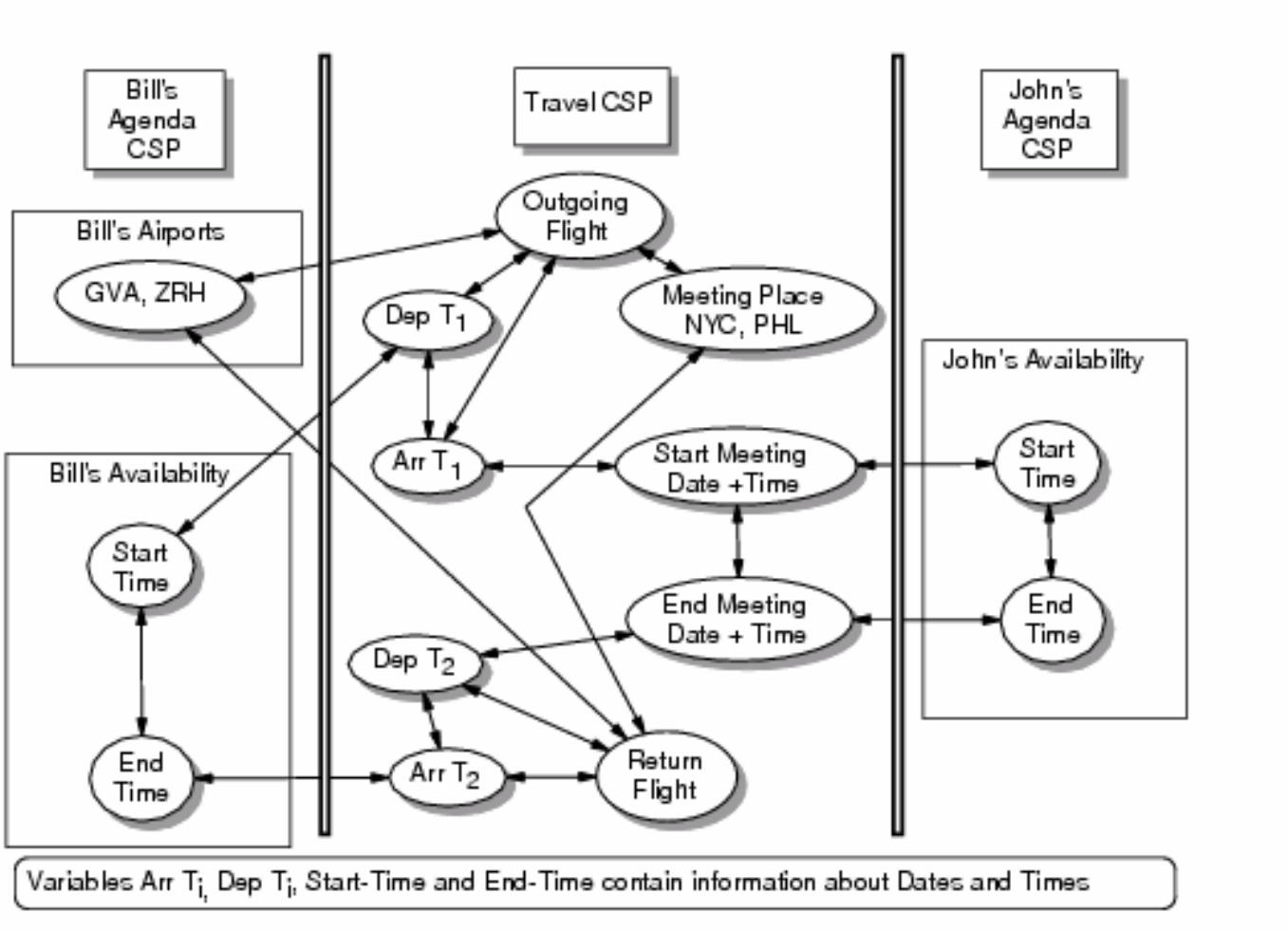
- A Constraint Satisfaction Problem (CSP) is:
  - a set of variables each with
  - a set of domain of values, and
  - a set of constraints that define which combinations of variable values are allowed
  - the task is to find a value for each variable such that all constraints are simultaneously satisfied
- Algorithms and techniques for solving CSPs have been widely studied

Conjunctive Normal Form: Example



- As a CSP:
  - Each clause is a constraint, each literal is a variable with a {true, false} domain
- $\{\neg x \vee \neg y \vee \neg z\} \wedge \{x \vee y \vee \neg z\} \wedge \{\neg x \vee y\} \wedge \{\neg y \vee z\}$
- To Solve:
  - All clauses evaluate true
  - e.g.: x = false, y = true, z = true

Example CSP Graph for Travel



Formalization of Example: Variables

- X = {DT_0,...DT_{n-1}, AT_0,...,AT_{n-1},$Airports_0$,...,$Airports_n$, $Flights_0$,...$Flights_{n-1}$,AirCrafts,Fares,Airlines,...} is a set of variables
  - DT_i and AT_i represent the dates and times on which the traveler could depart and arrive respectively
  - $Airports_i$ represents the possible airports near the departure for leg of the itinerary
  - $Flights_i$ stands for the possible flights between the aiports of $Airports_i$ and $Airports_{i+1}$

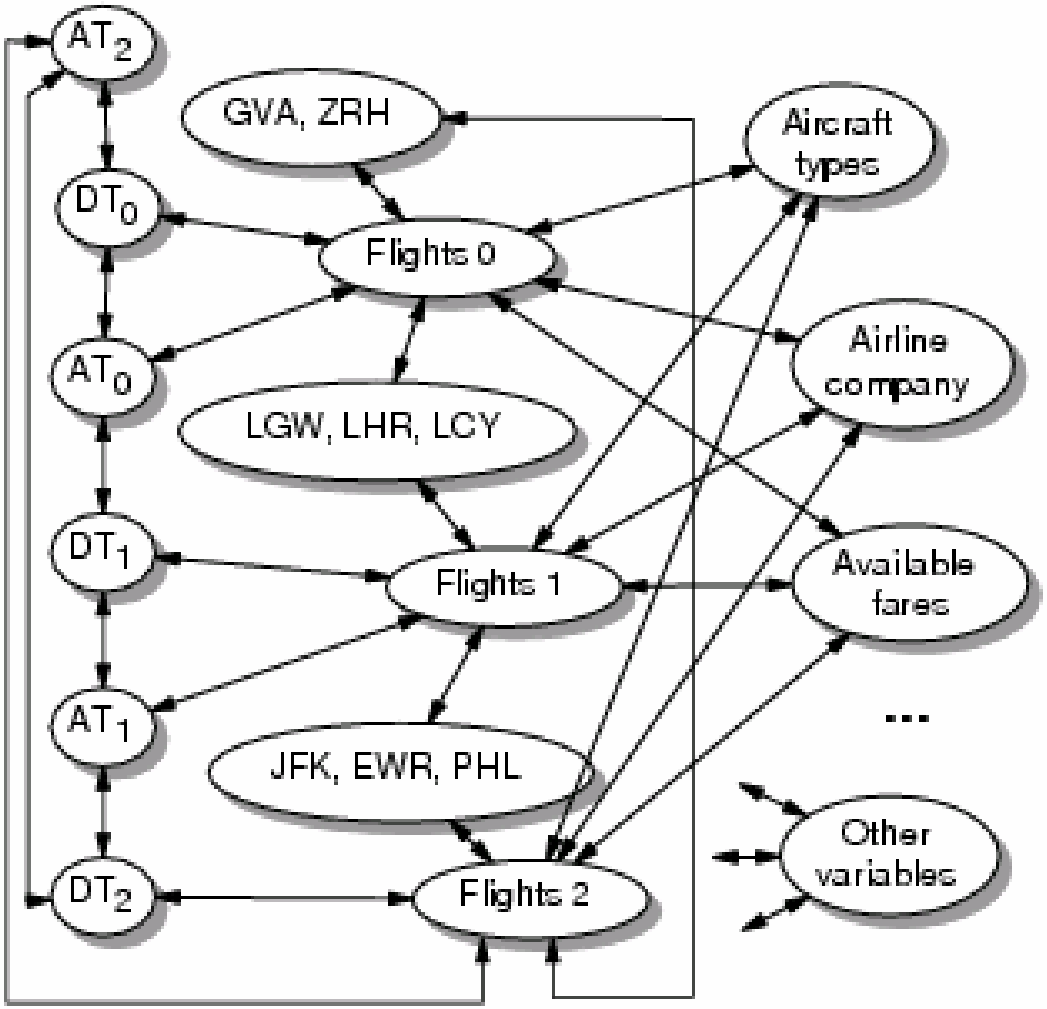
Formalization of Example: Domains

- $D = \{D_1,...,D_n\}$ is the set of domains
  - For variables DT_i or AT_i: the domain contains all possible departure and arrival times for the leg_i
  - For variables $Airports_i$: the domain is a set of airports for the departure of the leg_i
  - For variables $Flights_i$: the domain is the set of possible flights from $Airports_i$ to $Airports_{i+1}$
  - For variables AirCrafts, Fares and Airlines: the domain is the set of different aircrafts, the set of available fares or the set of airline companies respectively

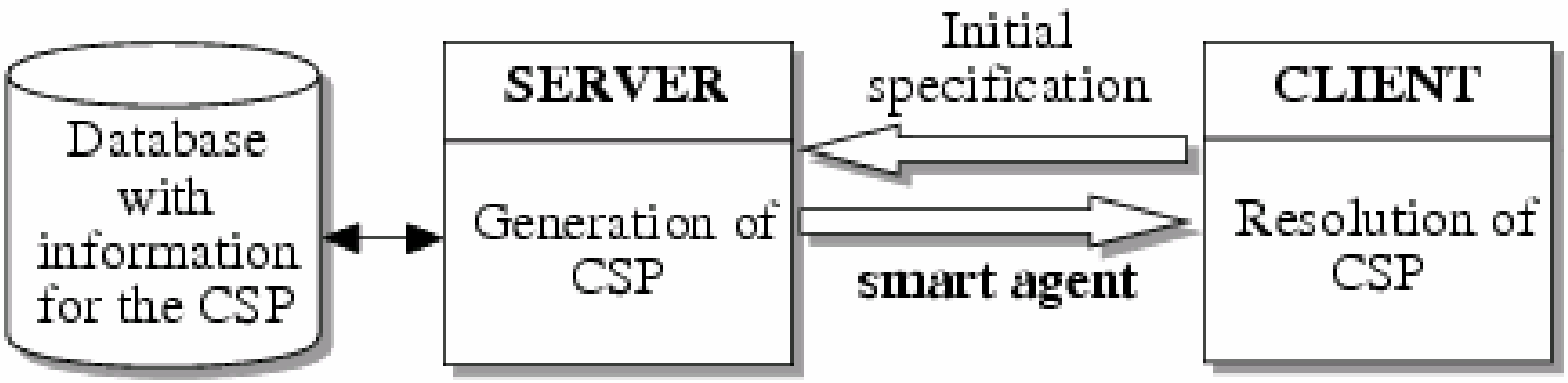
Formalization of Example: Constraints

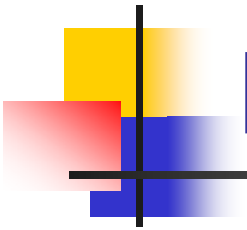
- $C = \{C_1,...,C_n\}$ is the set of constraints
  - Two types of constraints:
    - Those imposed by the user's preferences
    - Those imposed by flight schedules
  - There are constraints on the variables $Flights_i$, $Airports_i$, DT_i and AT_i that guarantee the the flight is compatible with the airports, departure times and arrival times
  - A binary constraint in between AT_i and DT_{i_1} takes into consideration that the flight for leg_{i+1} departs after the flight for leg_i arrives
  - User preferences are expresed by means of constraints between $Flight_i$ variables and Aircrafts, Airlines, Fares, and other variables

Constraint Graph for Flights



Architecture for SmartClients

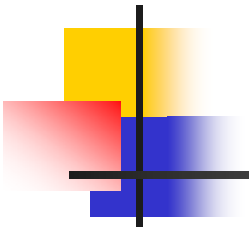




Pros and Cons

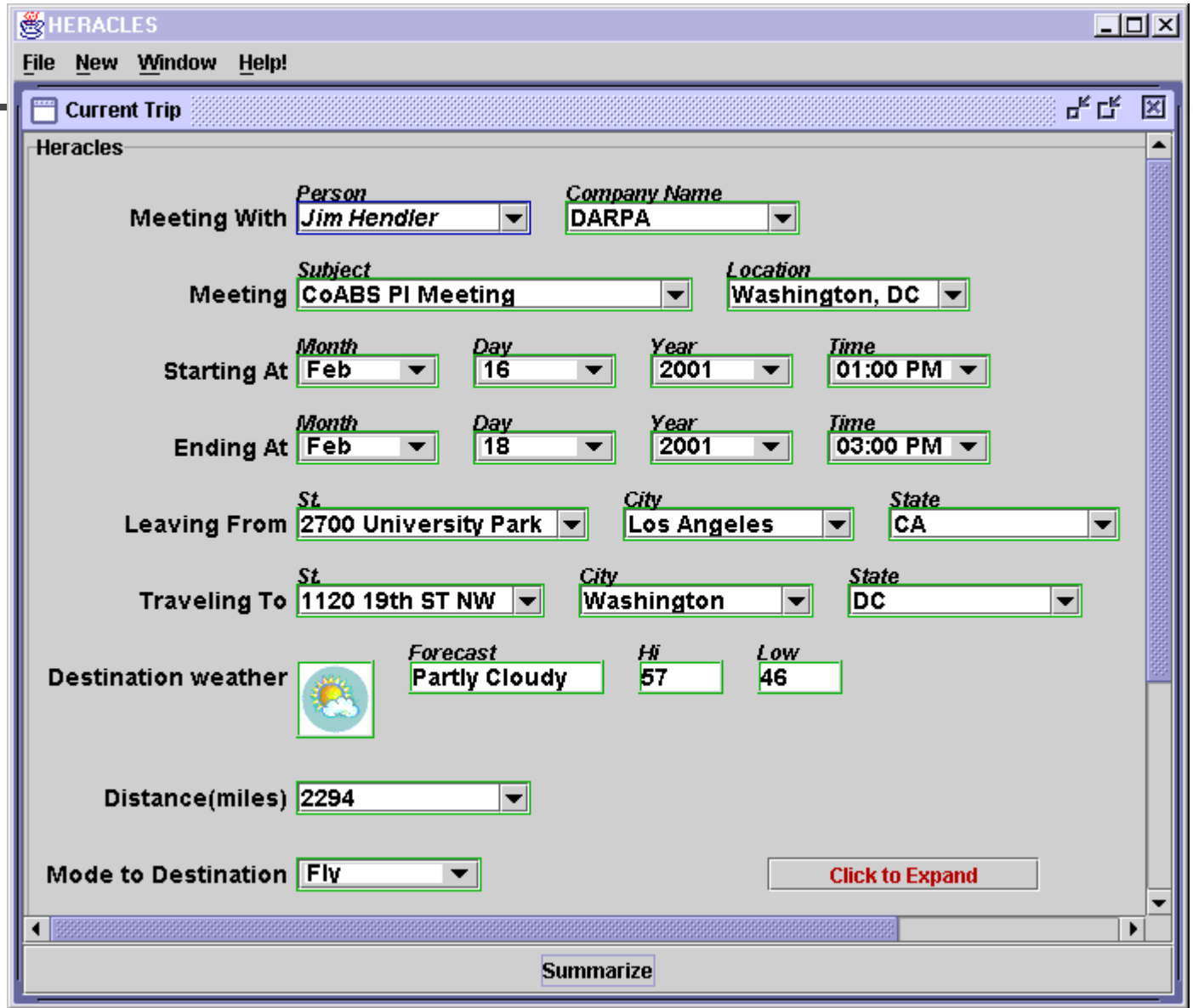
- Pros
  - Elegant approach that exploits past work on CSPs
  - Minimizes the data retrieval and supports complex reasoning and integration of the data
- Cons
  - Assumes that all data can be retrieved before any reasoning about the data
  - In the travel planning, assumes that prices are the same on any date and there are no issues with flight availability

Heracles Constraint Integration Framework

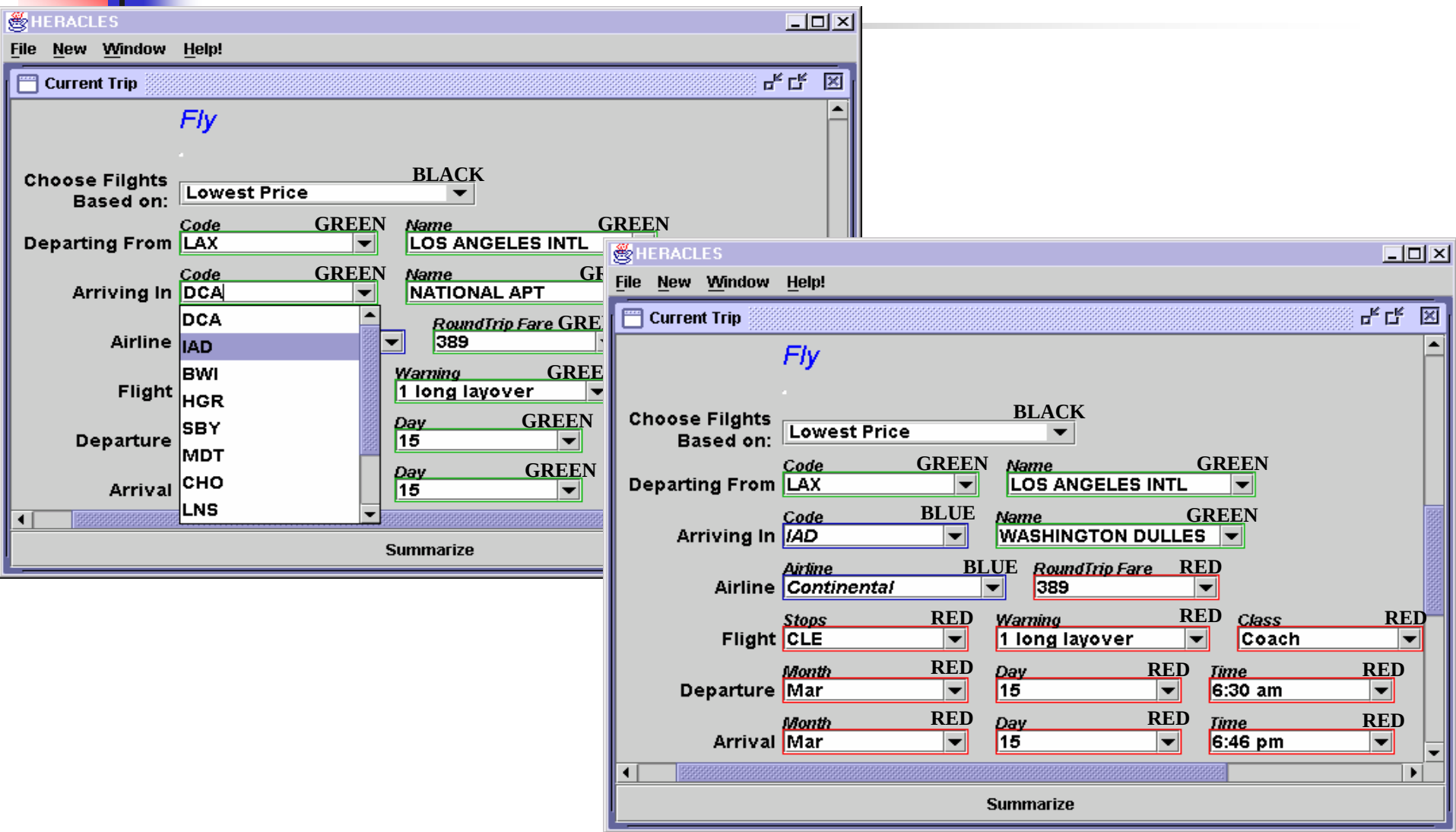


- Framework for building integrated applications
- Interleaves planning and information gathering
- Uses a constraint reasoner to decide what sources to query and to integrate the results

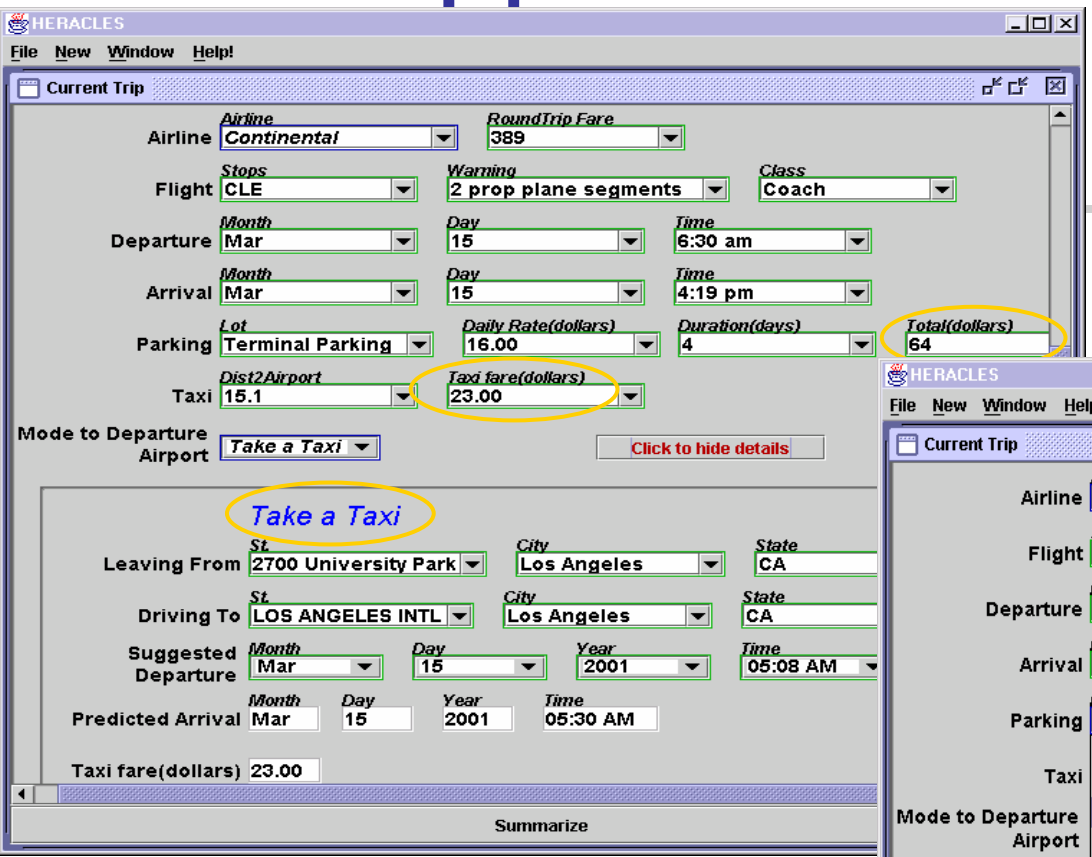
The Travel Assistant

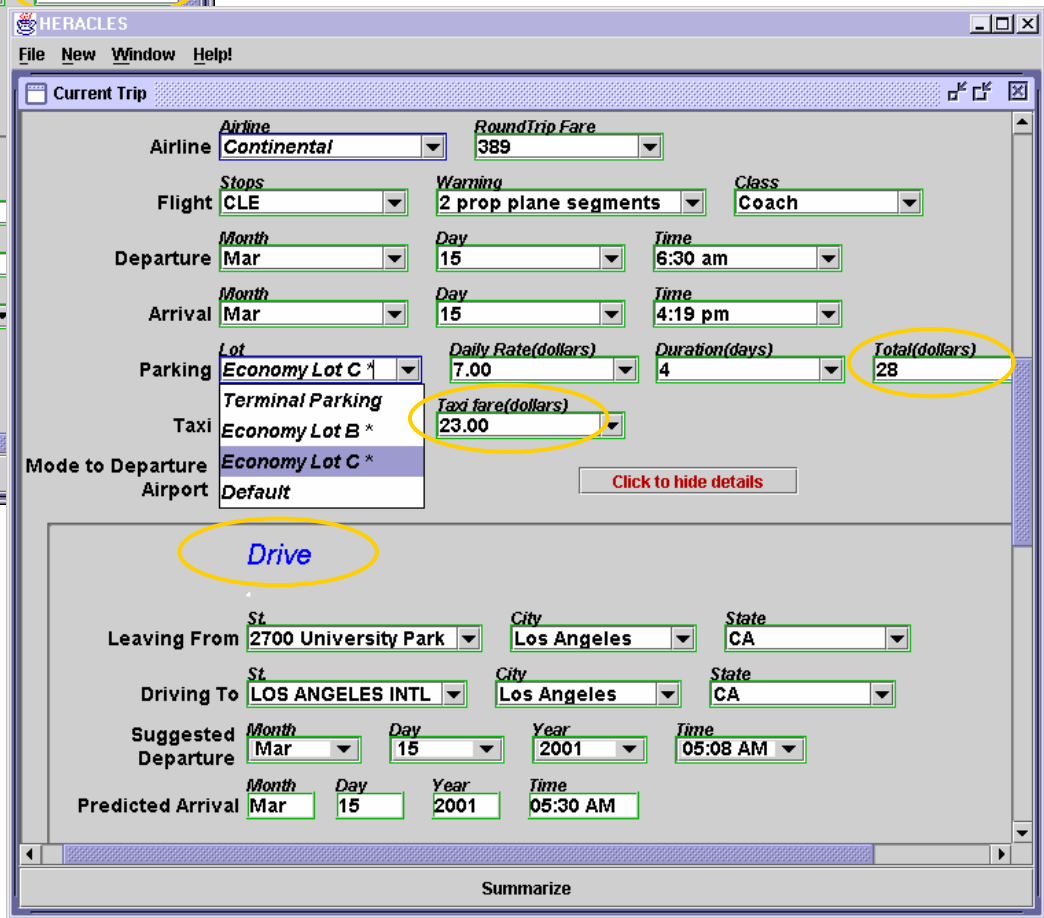


Dynamically Updates Slots as Information Becomes Available

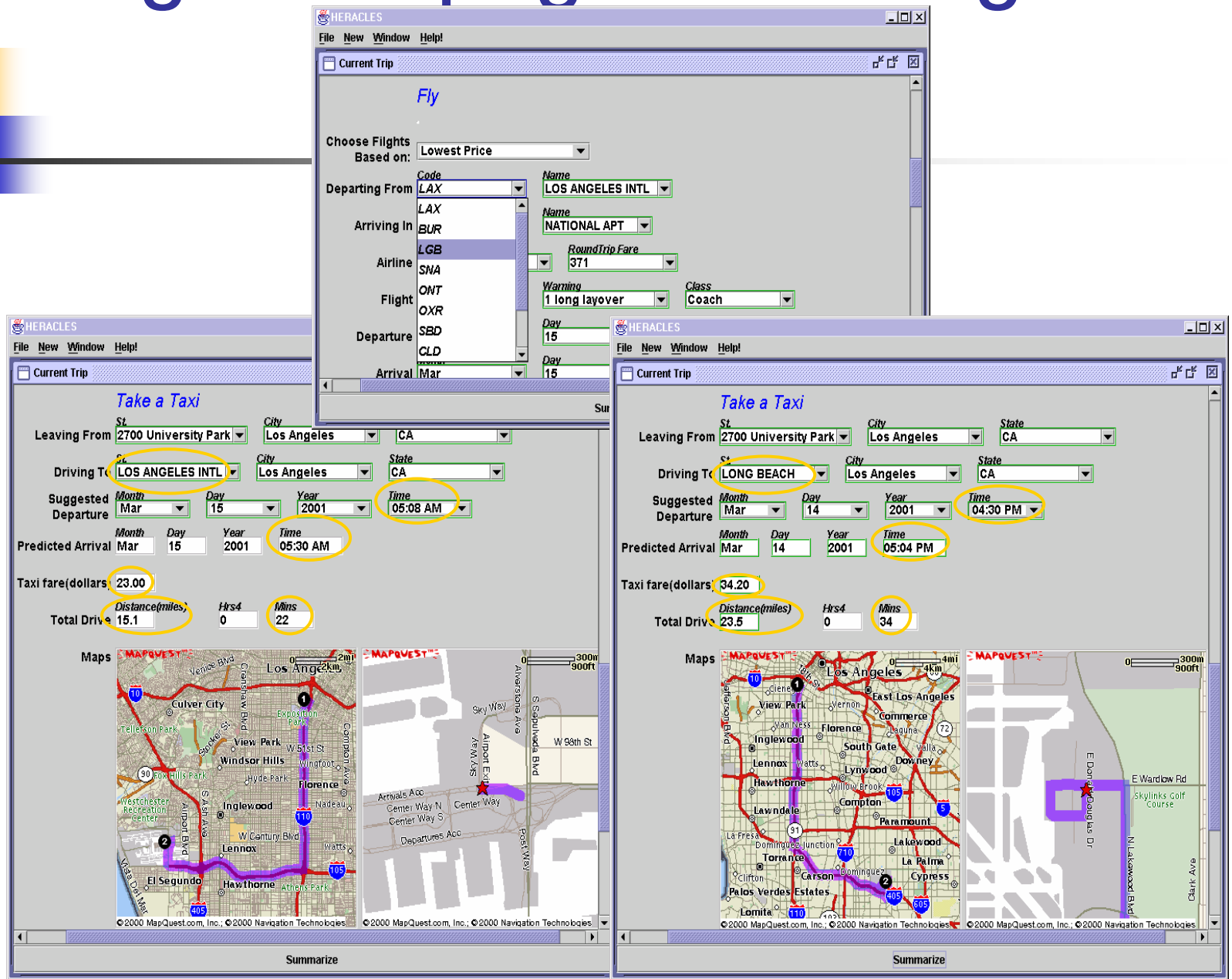


Supports Informed Choices

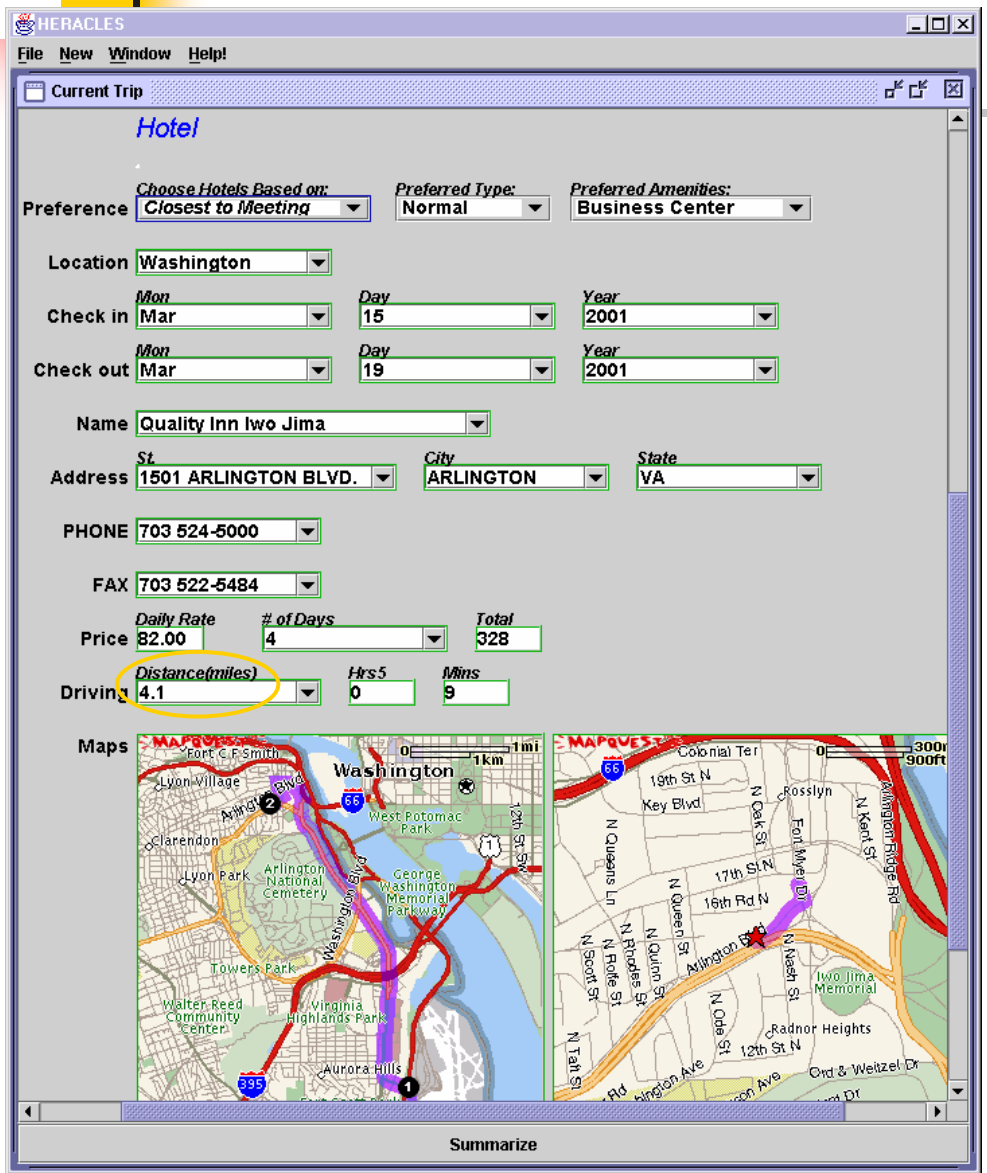


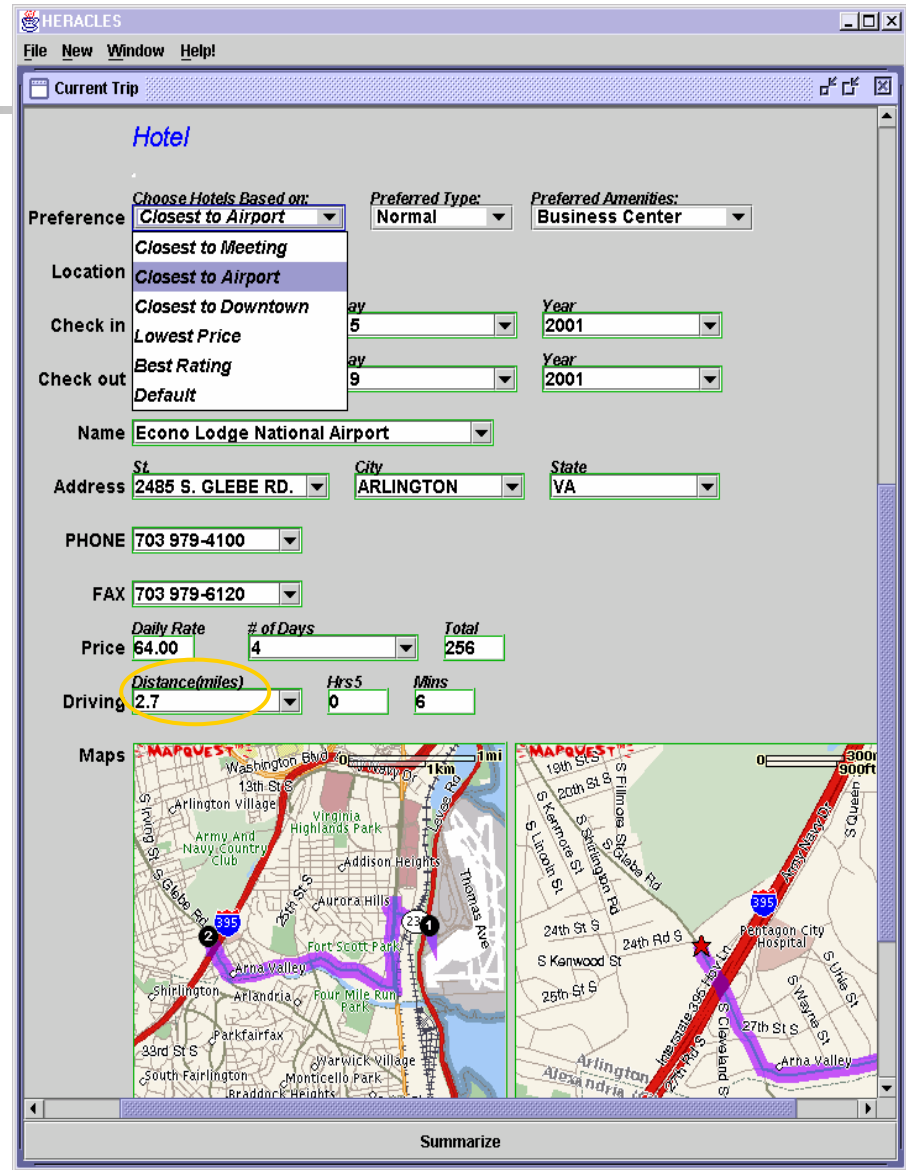


Changes Propagate Throughout

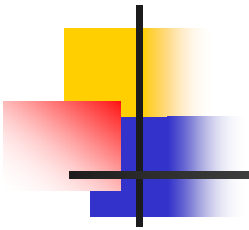


User Can Specify High-Level Preferences



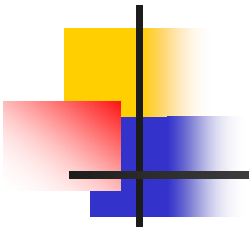


Constraint Networks for Integrating Information



- Components:
  - Representation of the variables
  - Representation of constraints
  - Hierarchical template representation
  - Constraint propagation and cycle detection

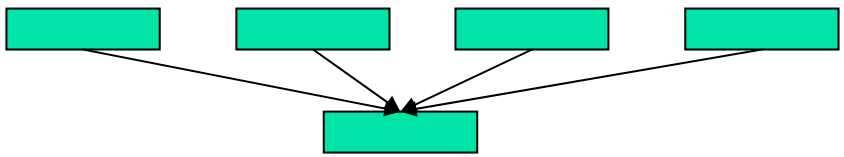
Constraint Networks for Integrating Information



- Components:
  - Representation of the variables
  - Representation of constraints
  - Hierarchical template representation
  - Constraint propagation and cycle detection

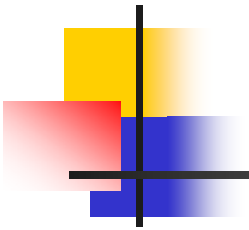
Constraint Variables

- Constraint network consists of a set of variables such as:
  - MeetingStartTime
  - MeetingLocation
- Each variable depends on a set of ancestors.



- Variables are related by constraints that determine the possible values of a solution

Constraint Networks for Integrating Information



- Components:
  - Representation of the variables
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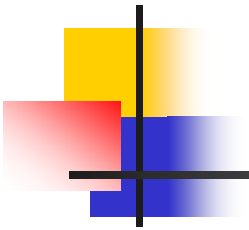
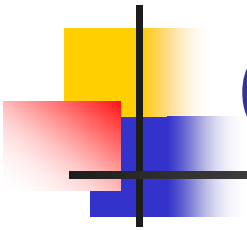
Constraint Representation



- Constraints are computable components:
  - Local calculations based on Xquery
    - MeetingStartTime + MeetingDuration --> MeetingEndTime
  - Web and Database Wrappers
    - ITN: DepartureAirport, ArrivalAirport, Date --> Flights
    - Yahoo Weather: City, Date --> Weather predication
  - External Programs (Outlook, Planners, etc)
    - Outlook Calendar: Date --> Meetings

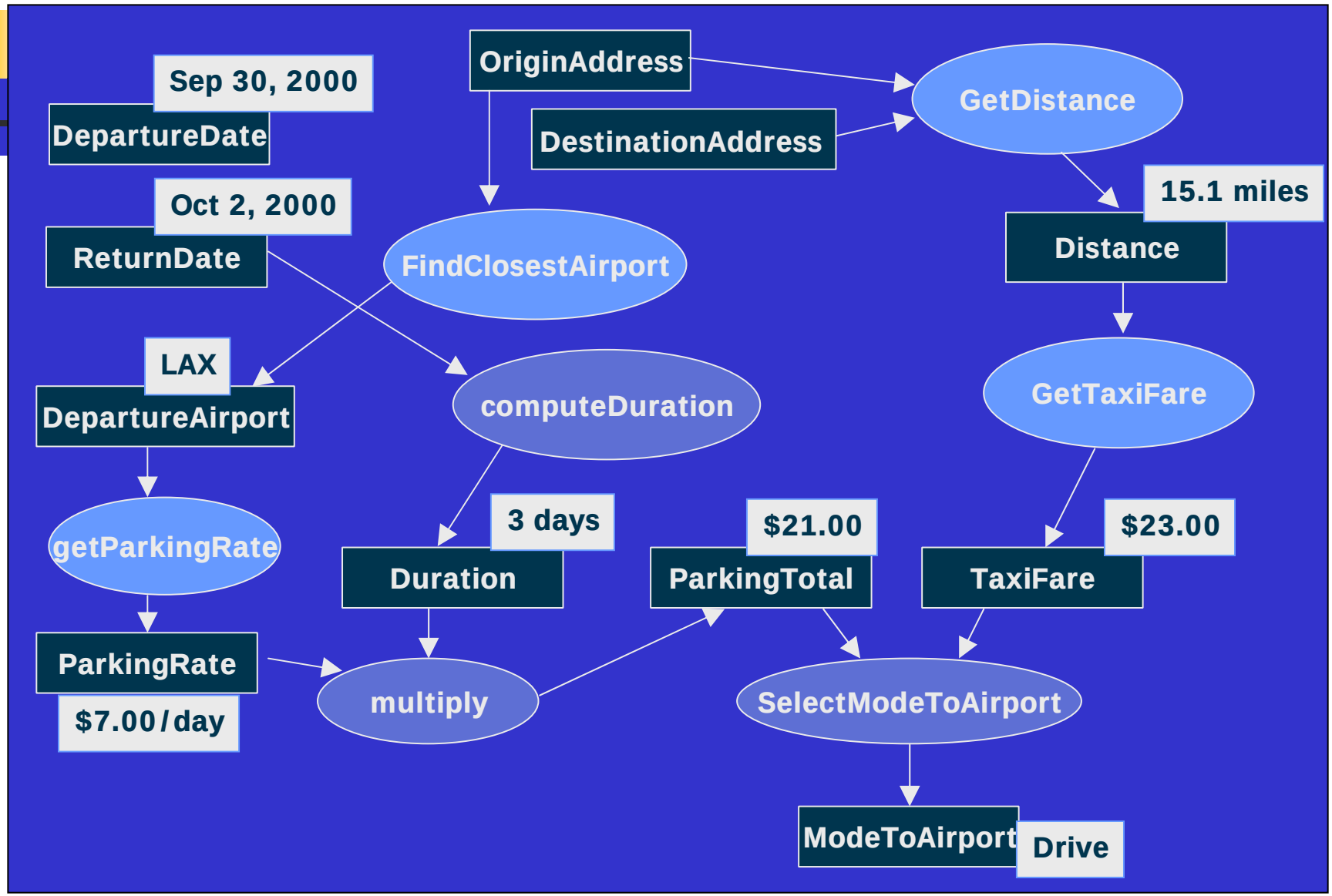


Constraint Structure

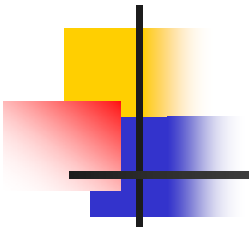
Constraint

- Arguments: input and output variables
- Call:
  - Construct table with inputs and corresponding calls (http requests, SQL queries, etc) to sources (wrappers, DBs, etc) [using XML Query]
  - Calls are executed and results stored in an table
- Output
  - Restructure source results into desired output [using XML Query]

Drive or Take a Taxi?

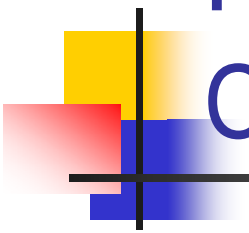


Constraint Networks for Integrating Information

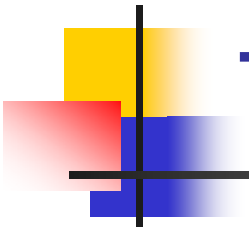


- Components:
  - Representation of the variables
  - Representation of constraints
  - Hierarchical template representation
  - Constraint propagation and cycle detection

Hierarchically-Partitioned Constraint Networks



- Template:
  - Groups related variables and constraints
  - Organizes information for computation and presentation to user
- Templates organized hierarchically
  - Template decomposed into subtemplates
  - Choose among alternative subtemplates

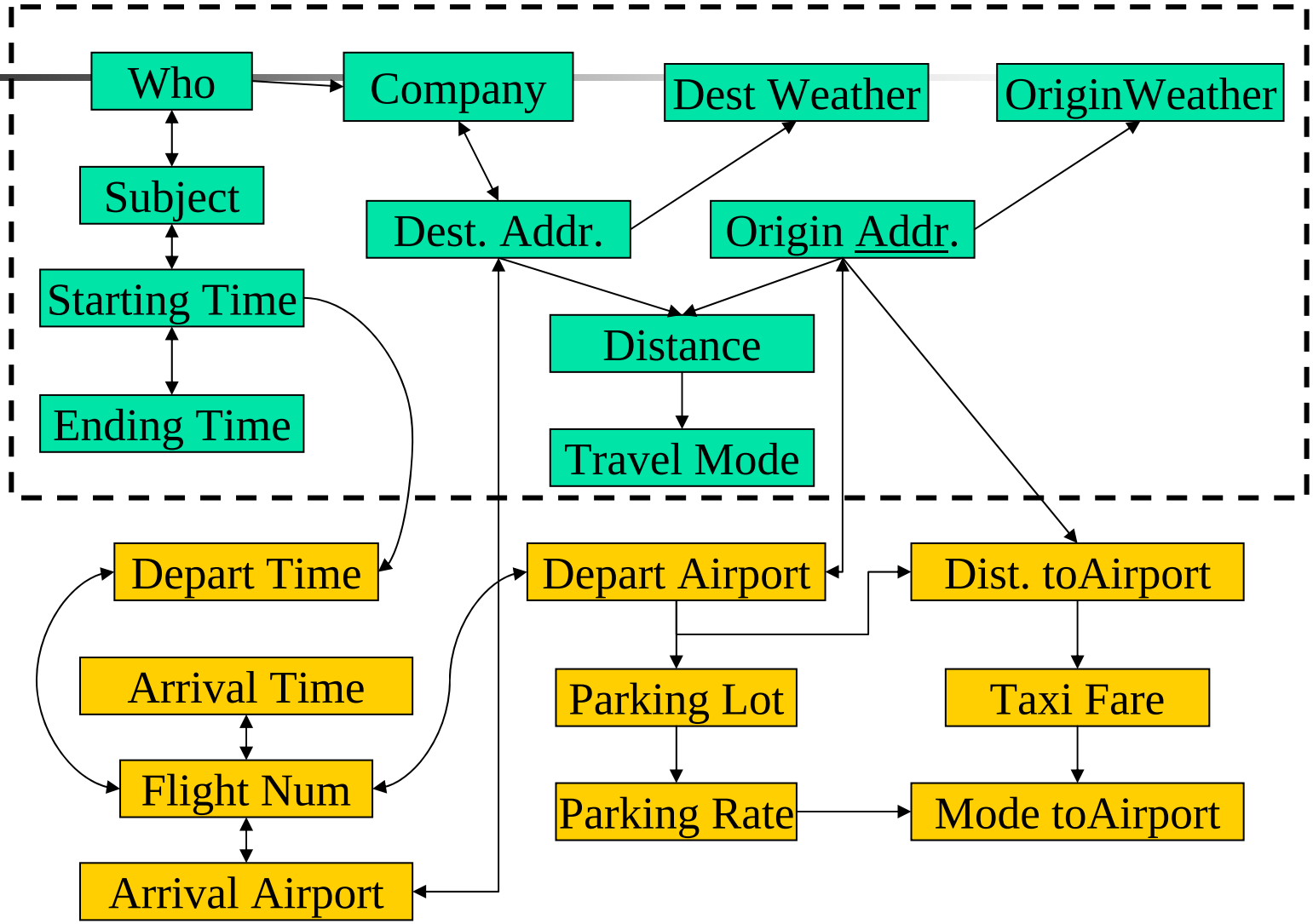


Template Structure

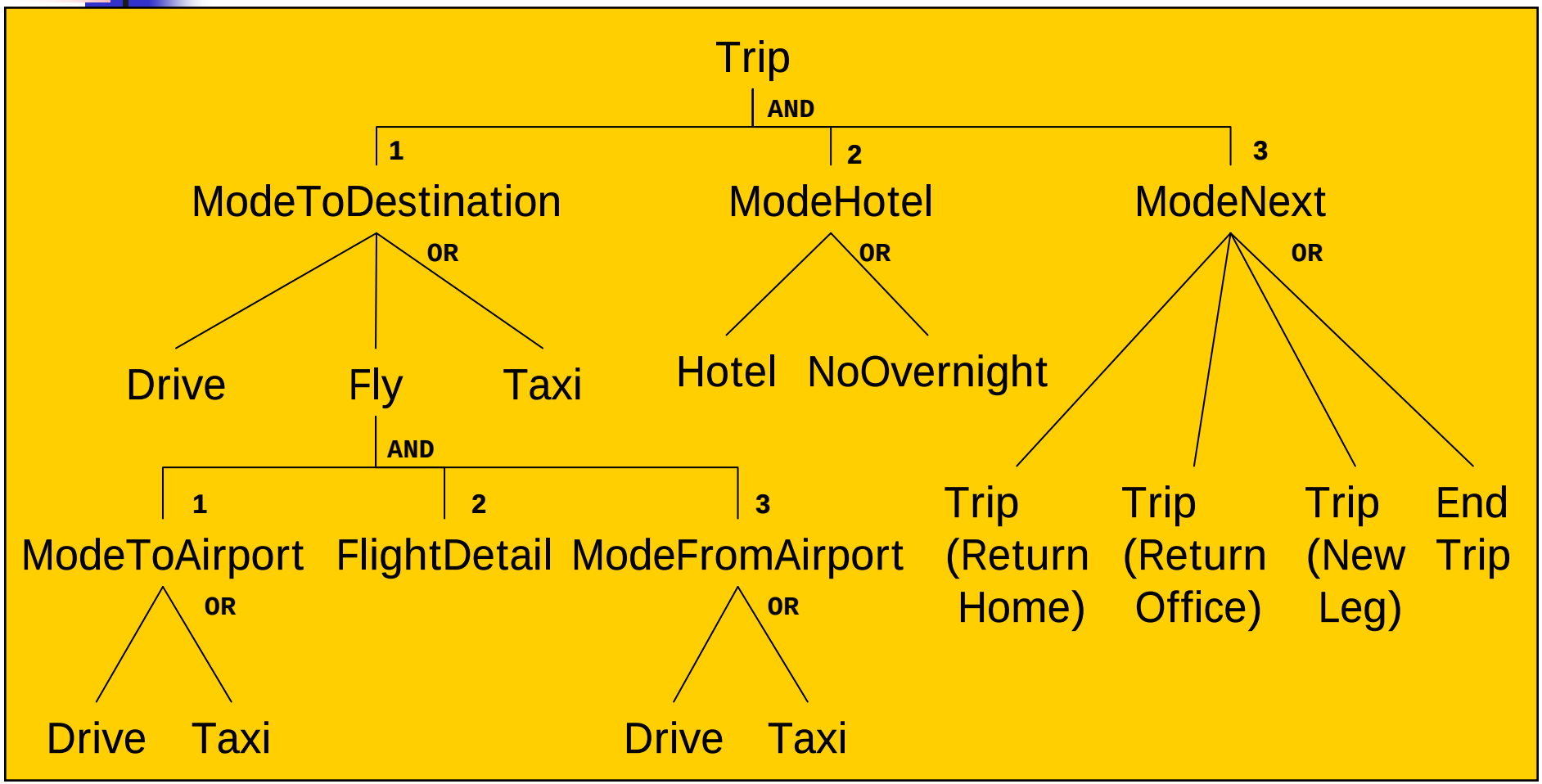
Template

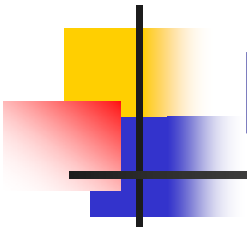
- Arguments: input and output variables
- Variables: name, type, default values
- Constraints
- Expansions: alternative subtemplate calls
- GUI specification

Partitioned Constraint Network



Template Hierarchy for the Travel Assistant





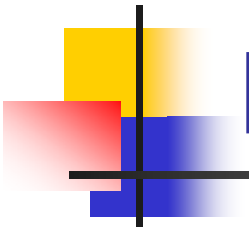
Dynamic Constraint Networks

Generalization of Constraint Networks

- Variables can be active or inactive
- Normal Constraints

  $x_1 = k_1 \wedge \ldots \wedge x_m = k_m \rightarrow x_n = k_n$
- Activity constraints:

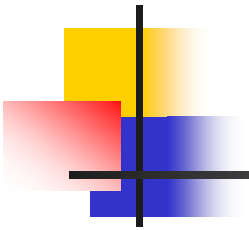
  $x_1 = k_1 \wedge \ldots \wedge x_m = k_m \rightarrow \text{active}(x_n)$
- Inactive variables do not participate in the network, i.e., do not propagate constraints



Heracles: Template Selection

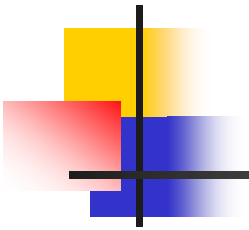
- Core network
  - Computes values of template selection vars
  - Always active
- Template selection variables
  - Inputs to activity constraints: determine the choice of subtemplates, i.e., which additional variables are active

Constraint Networks for Integrating Information

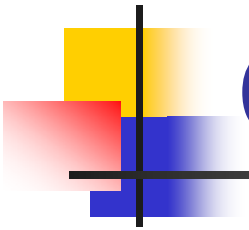


- Components:
  - Representation of the variables
  - Representation of constraints
  - Hierarchical template representation
  - Constraint propagation and cycle detection

Constraint Propagation



- Approach
  - When a variable is assigned a value, re-compute the value sets and assigned values of all dependent variables
  - Proceeds recursively until no values are changed or a cycle is detected
- Core network
  - Propagates all variables through the core network
  - Remaining variables are computing when a template is opened
- Does not perform full CSP
  - Less costly
  - Does not require all information in advance
  - Makes choices locally, so may fail to find optimal assignment

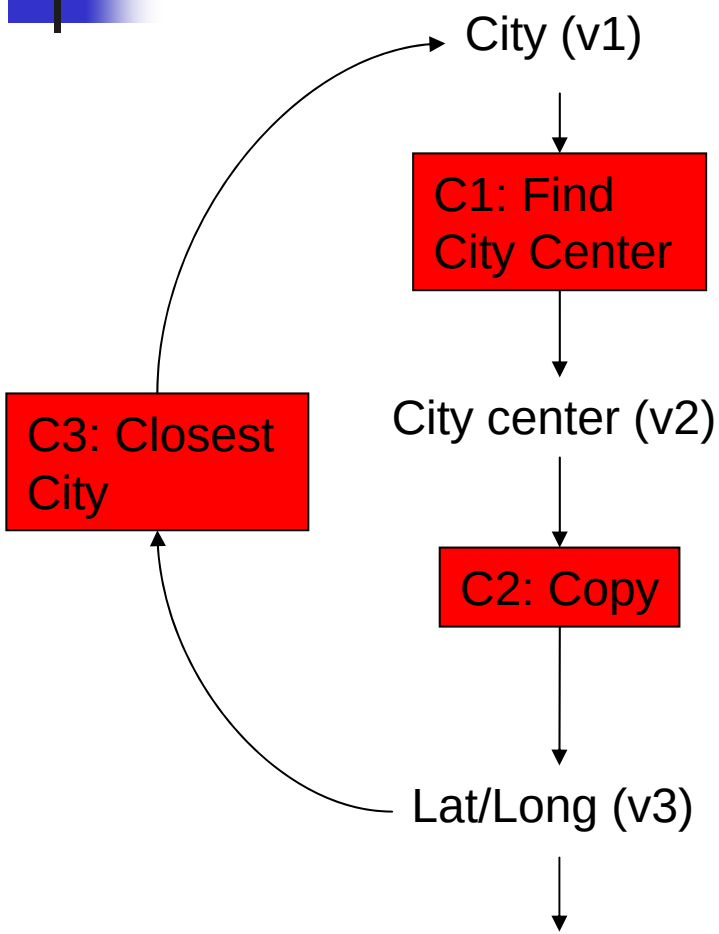


Cycle Detection

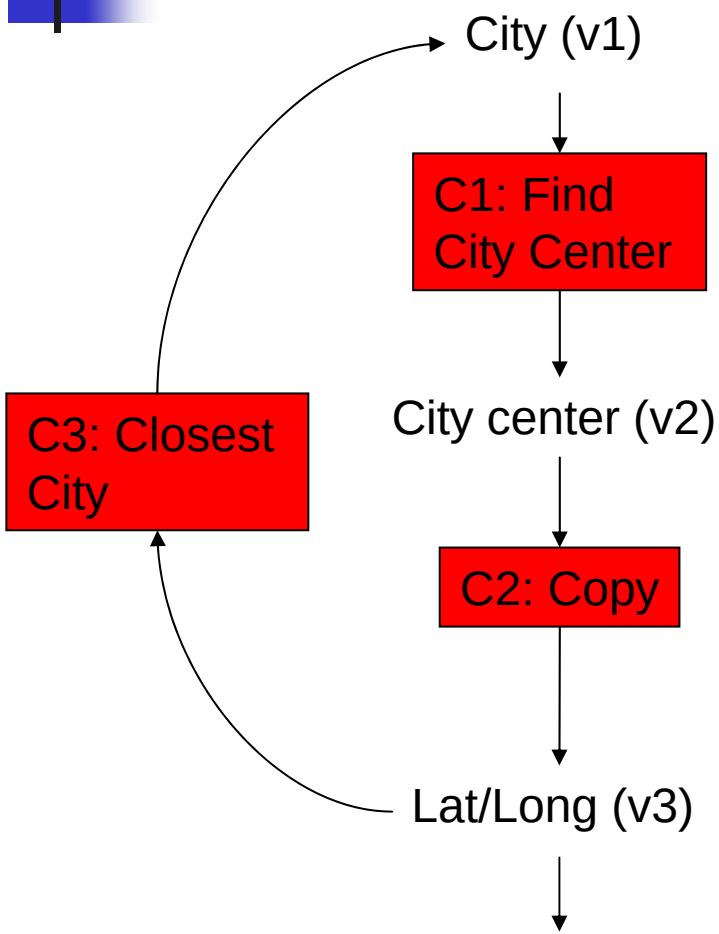
- Address cyclic *interactive* networks
  - Multiple input paths:
    - region/country/city vs. lat/long
  - Conversion rounding errors:
    - lat/long, temperature, ...

=> Cycle detection in constraint propagation

Interactive Cyclic Network

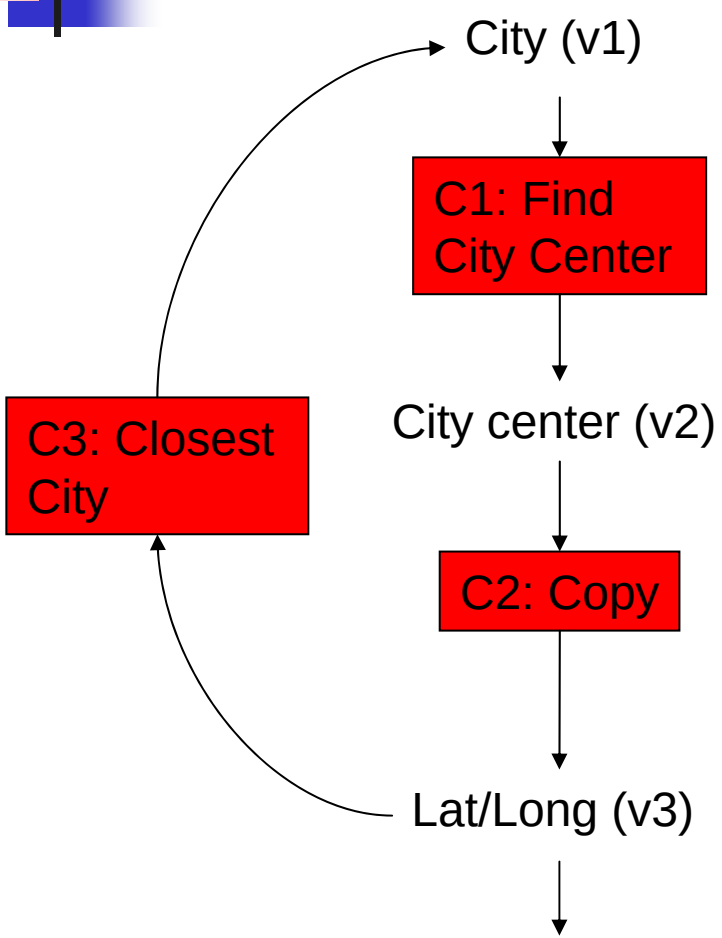


Interactive Cyclic Network



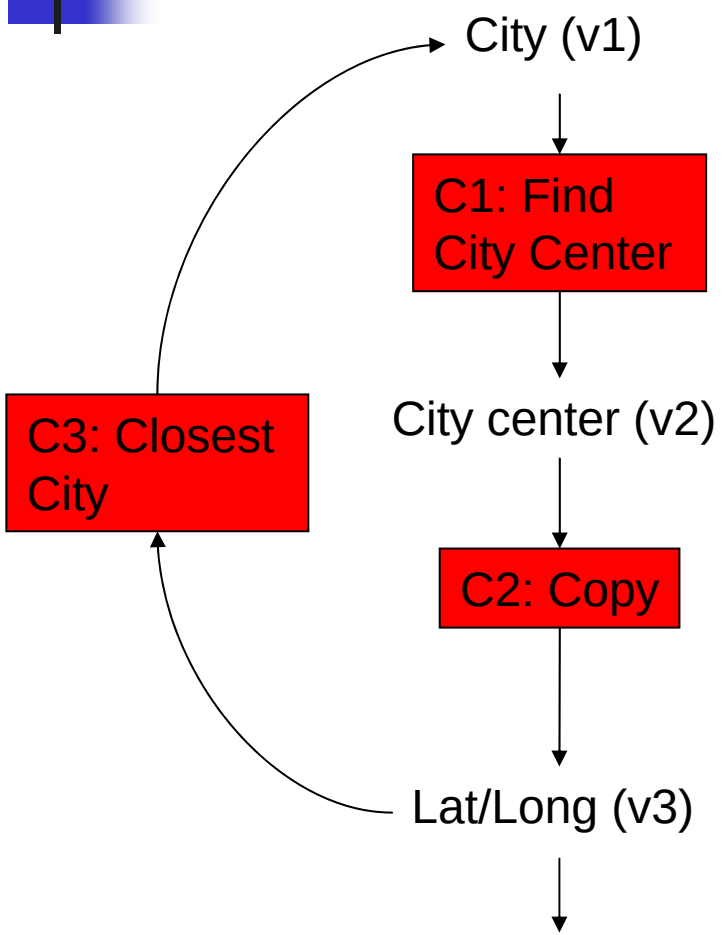
Sequence of events	User time	Visited Variables	Value
1)	1	Ø	LA

Interactive Cyclic Network



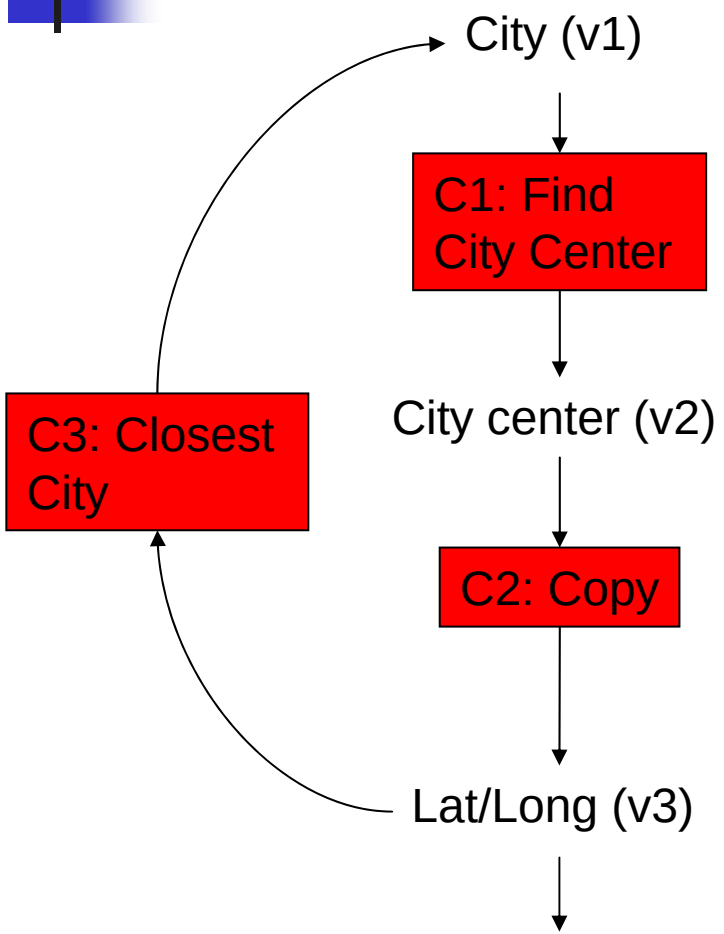
Sequence of events	User time	Visited Variables	Value
1)	1	Ø	LA
2)	1	v1	34N118W

Interactive Cyclic Network



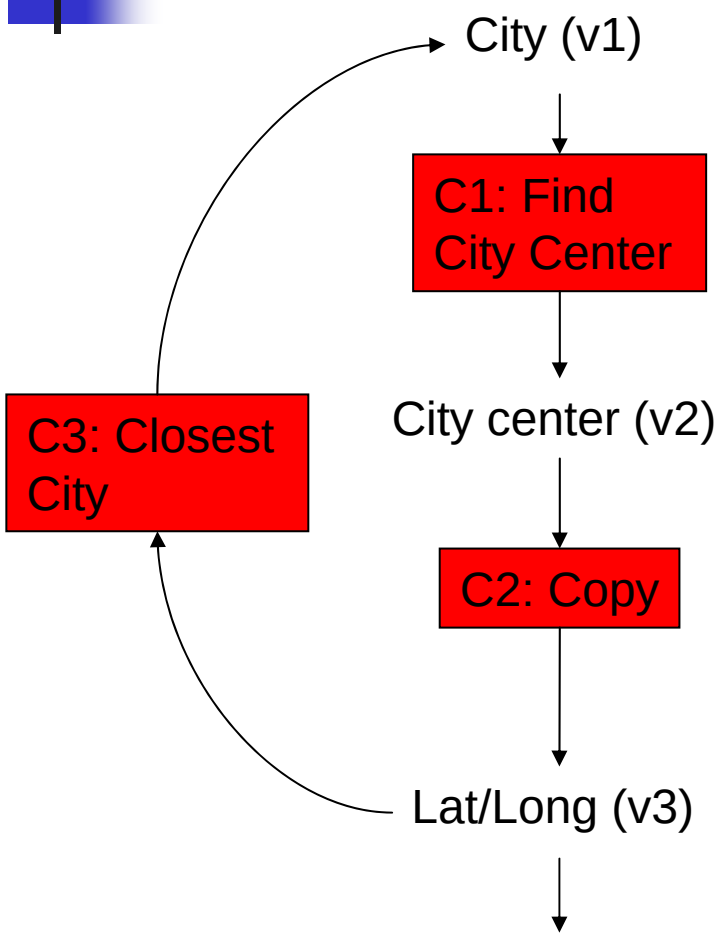
Sequence of events	User time	Visited Variables	Value
1)	1	Ø	LA
2)	1	v1	34N118W
3)	1	v1 v2	34N118W

Interactive Cyclic Network



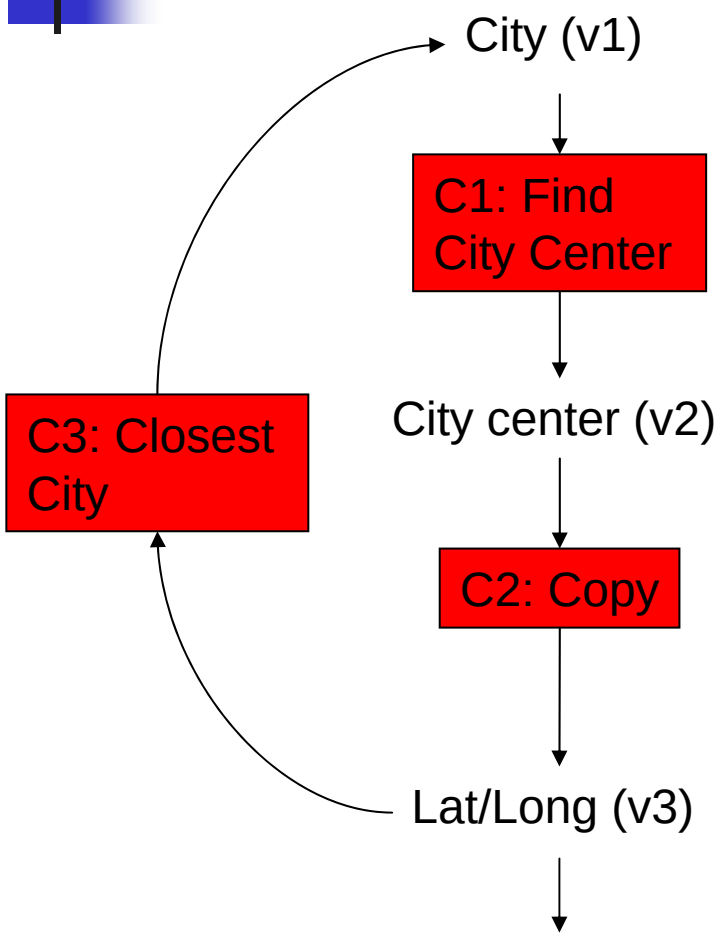
Sequence of events	User time	Visited Variables	Value
1)	1	Ø	LA
4)	Blocked!	**t(v3) = t(v1) ^ v1 ∈ vis(v3)**	
2)	1	v1	34N118W
3)	1	v1 v2	34N118W

Interactive Cyclic Network



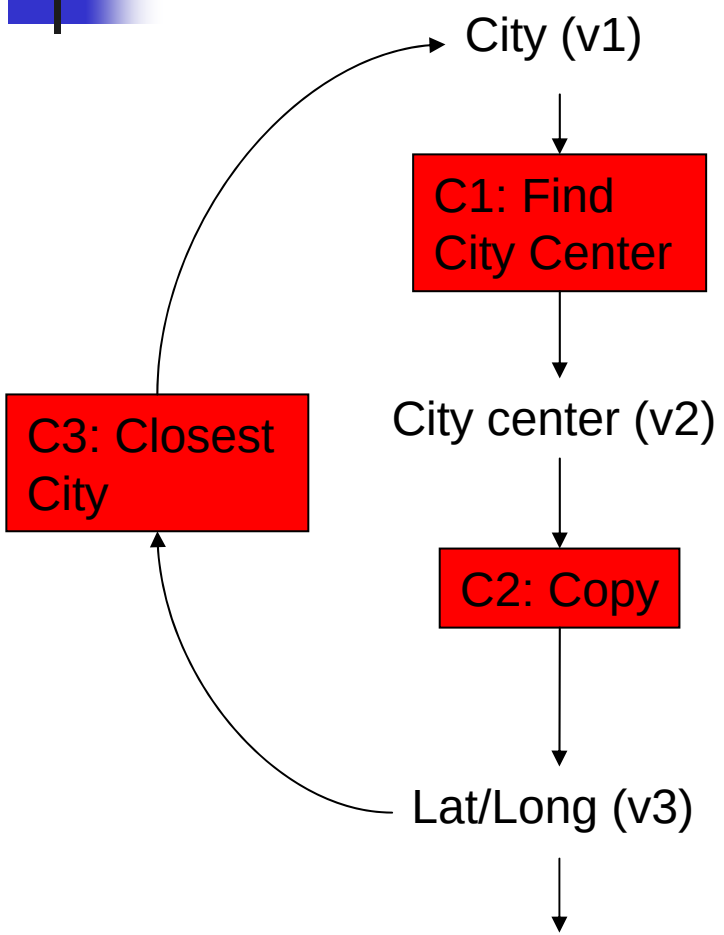
Sequence of events	User time	Visited Variables	Value
1)	1	Ø	LA
4)	Blocked!	**t(v3) = t(v1) ^ v1 ∈ vis(v3)**	
2)	1	v1	34N118W
3)	1	v1 v2	34N118W
5)	2	Ø	40N70W

Interactive Cyclic Network



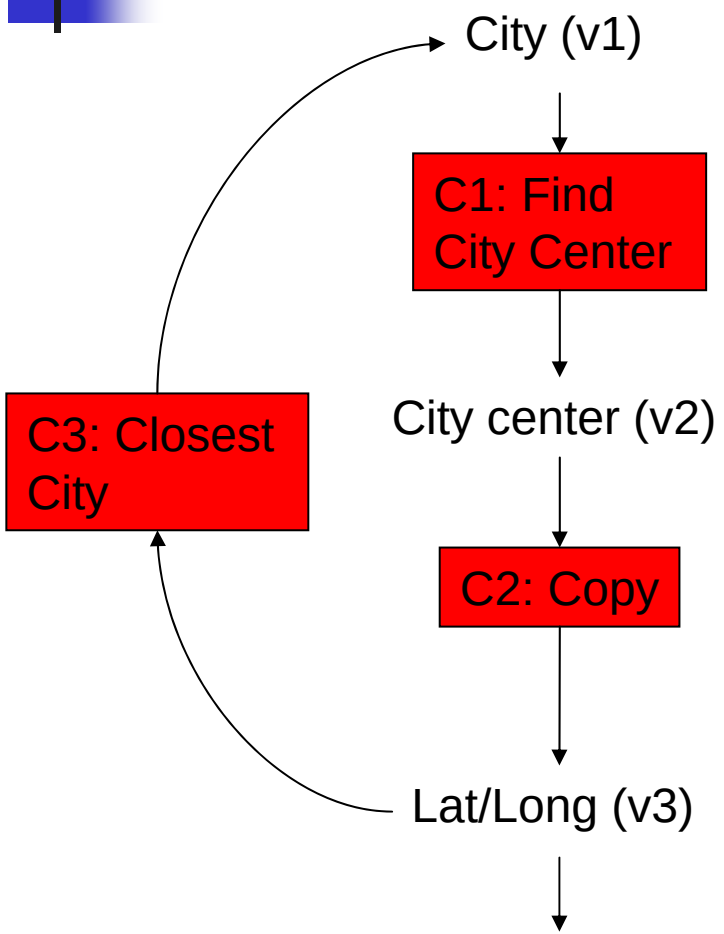
Sequence of events	User time	Visited Variables	Value
1)	1	Ø	LA
4)	Blocked!	**t(v3) = t(v1) ^ v1 ∈ vis(v3)**	
6)	2	v3	NY
2)	1	v1	34N118W
3)	1	v1 v2	34N118W
5)	2	Ø	40N70W

Interactive Cyclic Network

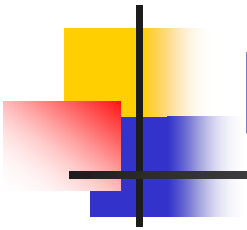


Sequence of events	User time	Visited Variables	Value
1)	1	Ø	LA
4)	Blocked!	**t(v3) = t(v1) ^ v1 ∈ vis(v3)**	
6)	2	v3	NY
2)	1	v1	34N118W
7)	2	v3 v1	40N73W
3)	1	v1 v2	34N118W
5)	2	Ø	40N70W

Interactive Cyclic Network



Sequence of events	User time	Visited Variables	Value
1)	1	Ø	LA
4)	Blocked!	**t(v3) = t(v1) ^ v1 ∈ vis(v3)**	
6)	2	v3	NY
2)	1	v1	34N118W
7)	2	v3 v1	40N73W
3)	1	v1 v2	34N118W
5)	2	Ø	40N70W
8)	Blocked!	**t(v3) = t(v2) ^ v3 ∈ vis(v2)**	



Discussion

- General framework for interleaving planning and information gathering
  - Retrieves information as needed
  - Gathers and integrates data in a uniform framework
  - Evaluates tradeoffs and selects among alternatives
  - Allows the users to explore alternatives
  - Supports a wide variety of information types: databases, web pages, images, video, etc.