Rules in production system

Example – the greatest common factor of two integers

gcf(0,a)=gcf(a,0)=a

if a>b then gcf(a,b)=gcf(a-b,b)

else gcf(a,b)=gcf(a,b-a)

initial WM (gcf val1:6 val2:9)

1. IF (gcf val1:x val2:y) THEN ADD(prod val:[x*y] val1:x val2:y)
   REMOVE 1
2. IF (prod val:0 val1:x val2:y) THEN ADD(res val:[x+y])
   REMOVE 1
3. IF(prod val:{≠0} val1:x val2:y) (prod val1:{>y}) THEN MODIFY 1 (val1 [x-y])
4. IF(prod val:{≠0} val1:x val2:y) (prod val1:{≤y}) THEN MODIFY 1 (val2 [y-x])

final WM (res val:3)

All conditions are disjoint, one rule fires at a time.

Rules in production system – solving conflicts

There are conflict resolution strategies to eliminate some applicable rules, if necessary.

The most common approaches are:

- Order: choose the first applicable rule in order of presentation (this strategy is implemented in PROLOG)
- Specificity: choose the applicable rule whose conditions are most specific

IF (bird) THEN ADD (cannotFly)

More specific than the first

IF (bird weight:{>100}) THEN ADD (cannotFly)

IF (bird)(penguin) THEN ADD (cannotFly)

Another criterion should be applied further to choose between the two rules

- Recency: choose the applicable rule that matches the most/least recently created/modified WME
- Refractoriness: reject a rule that has just been applied with the same value of its variables – it prevents going into loops by repeated firing of a rule because of the same WME.

Rules in production system – efficiency

The rule matching operation consumes up to 90% of the operating time of a production system.

Two key observations led to a very efficient implementation:

- WM modifies very little during an execution cycle
- Many rules share common conditions

The RETE algorithm (Charles L. Forgy of Carnegie Mellon University, 1974) creates a network from the rules antecedents. This network can be created in advance, as the rules do not change during the system operation.

During operation, new or changed WMEs are checked if they satisfy the conditions of a rule. In this way, only a small part of WM is re-matched against the conditions of the rules, reducing drastically the time to calculate the applicable rules.

CLIPS (C Language Integrated Production System) based on RETE – for building expert systems

Rules in production system – advantages

- Modularity – because the rules work independently, they can be added or deleted relatively easily – but for large system, this advantage fades away
- Control – a (relatively) simple control structure
- Transparency – the rules use a terminology easy to understand and the reasoning can be traced and explained in natural language

Production systems are used in a wide variety of practical problems (e.g. medical diagnosis, checking for eligibility for credits, configuration of systems).

Rules in production system – applications

MYCIN – expert system for diagnosis of bacterial infections, developed at Stanford University in '70

– 500 production rules for recognizing 100 causes of infections

– the most significant contribution was the introduction of a level of certainty of evidences and confidence in hypothesis

XCON – rule-based system for configuring computers, developed at Carnegie Mellon University in 1978

– 10000 rules to describe hundreds of types of components

– contributed to a growing commercial interest in rule-based expert systems.

Frames – object-oriented representation

FOL and production systems are representation methods that are “flat”, in the sense that each representation unit is independent of the others.

Knowledge about an object could be scattered all over the knowledge base, among unrelated sentences. In big KBs, this can become critical, therefore it is important to organize knowledge representation somehow.

In 1975, Marvin Minsky introduced “frames” as knowledge representation for object-oriented groups of procedures to recognize and deal with new situations.

In representations using frames, facts and rules are grouped in terms of the kind of objects they belong to. Thus, knowledge is not seen as just a collection of sentences, but rather it is structured in terms of what knowledge is about (i.e. the objects of knowledge).

Frames – object-oriented representation

Generic and individual frames

Individual frames represent objects; generic frames represent categories of classes of objects.

Individual frames are similar to WMEs in production systems. An individual frame is a named list of slots into which values, called fillers, can be dropped:

(Frame_name
<slot_name1 filler1>
<slot_name2 filler2>
…)

The names of individual frames begin with a lower-case; the names of generic frames begin with upper-case.

Fillers are atomic values (numbers or strings) or names of other individual frames or generic frames.

Slot names begin with upper-case and are prefixed with :

Frames – object-oriented representation

Examples

(CanadianCity
<:IS-A City>
<:Province CanadianProvince>
<:Country canada>)

(toronto
<:INSTANCE-OF CanadianCity>
<:Province ontario>
<:Population 4.5M>…)

Frames – object-oriented representation

Examples

(CanadianCity

<:IS-A City>

<:Province CanadianProvince>

<:Country canada>)

(toronto

<:INSTANCE-OF CanadianCity>

<:Province ontario>

<:Population 4.5M>…)

Individual frames have a special slot called :INSTANCE-OF, whose filler is the name of a generic frame which indicates the category of the object represented by that individual frame (the individual frame is an instance of the generic frame).

Generic frames have a special slot called :IS-A, whose filler is the name of a more general generic frame. We say that the generic frame is a specialization of the more general one.

Frames – object-oriented representation

Slots of generic frames can have attached procedures IF-ADDED and IF-NEEDED.

The rule Parent(x,y)<=Mother(x,y) can be procedurally interpreted as following:

IF-NEEDED – whenever we have to solve a goal that matches Parent(x,y), we reduce it to solving Mother(x,y) (backward chaining). Procedurally, the connection between mothers and parents is made when we must prove something about parents.

IF-ADDED – whenever a fact that matches Mother(x,y) is added to the KB, we also add Parent(x,y) (forward chaining). The connection between mothers and parents is made when we know something new about Mother(x,y).

Frames – object-oriented representation

(Trip

<:TotalCost [IF-NEEDED ComputeCost]>…)

(Lecture

<:DayOfWeek WeekDay>

<:Date [IF-ADDED ComputeDayofWeek]>…)

A slot can have both a filler and an (inherited) attached procedure in the same frame.

Frames – object-oriented representation

Inheritance

In a frame system, the reasoning involves creating individual instances of generic frames and filling/inferring values into slots. Generic frames can be used to fill in values that are not explicitly given at the creation of the instances. Generic frames can also trigger additional actions when fillers are provided. We can determine a value in an instance by inheritance (the child frames inherit properties from their parents frame).

For example, if we are interested in the filler for the slot :Country of the toronto frame, we can use :INSTANCE-OF that indicates to the generic frame CanadianCity, where the value is given (toronto inherits the :Country property from CanadianCity).

If toronto had not a filler for :Province, we should still know by inheritance that we should look for an instance of CanadianProvince.

Frames – object-oriented representation

Inheritance of attached procedures

(ExpensiveTrip
 <:IS-A Trip>…)

(Trip
 <:TotalCost [IF-NEEDED ComputeCost]>…)

(ExoticExpensiveTrip
 <:IS-A ExpensiveTrip >…)

If we create an instance of the frame Trip and we want to find a filler for :TotalCost in this instance, we use the attached procedure IF-NEEDED.

The same procedure can be used through inheritance if we create an instance of ExoticExpensiveTrip.

Frames – object-oriented representation

Inheritance of attached procedures

If we create an instance of the frame Lecture with the data specified explicitly:

(lecture1
<:INSTANCE-OF Lecture>
<:Date 20Nov>…)

(Lecture
<:DayOfWeek WeekDay>
<:Date [IF-ADDED ComputeDayofWeek]>…)

Then the attached IF-ADDED procedure would be executed, filling the slot :DayOfWeek.

If we later change the :Date slot, the procedure will execute again, changing the filler for :DayOfWeek.

Frames – object-oriented representation

In a frame system, we use an inherited value only if we cannot find a filler otherwise (it is defeasible).

A slot filler in a generic frame can be overridden explicitly in its instances and its specializations:

(Elephant
<:IS-A Mammal>
<:EarSize large>
<:Color gray>…)

(raja
<INSTANCE-OF Elephant>
<EarSize small>…)

(RoyalElephant
<IS_A Elephant>
<:Color white>…)

(clyde
<:INSTANCE-OF RoyalElephant>…)

A frame system allows for multiple inheritance. An individual/generic frame can be an instance/a specialization of more than one generic frame.

(AfricanElephant
<:IS-A Elephant>
<:IS-A AfricanAnimal>…)

[for more on Inheritance, see Chapter 10 in Brachman&Levesque]

Frames – object-oriented representation

Reasoning with frames

In a frame system, reasoning starts when the system recognizes an object being an instance of a generic frame and applies the procedures triggered by that instance. These procedures can produce new data or changes in the KB. The system operation stops when no more procedures are applicable.

The system operates in a three-step loop:

1. Someone (a user or an external system) declares that an object exists, instantiating a generic frame.
2. Any slot fillers that are not provided explicitly, but can be inherited by the new instance, are inherited.
3. For each slot with a filler, if an IF-ADDED procedure can be inherited, then it is executed. By its execution, new slots can be filled or new frames can be instantiated; then go to 1.

Frames – object-oriented representation

If a filler is requested by a user, an external system or an attached procedure, then:

1. If the filler exists, then the value is returned;
2. Otherwise, any IF-NEEDED procedure that can be inherited is executed, computing the filler. The execution can also fill other slots or instantiate new frames.

If no result is produced by the steps above, then the value of the slot is unknown.

Obs. The inheritance of the values is done when the individual frame is created, but IF-NEEDED procedures are invoked only by request.

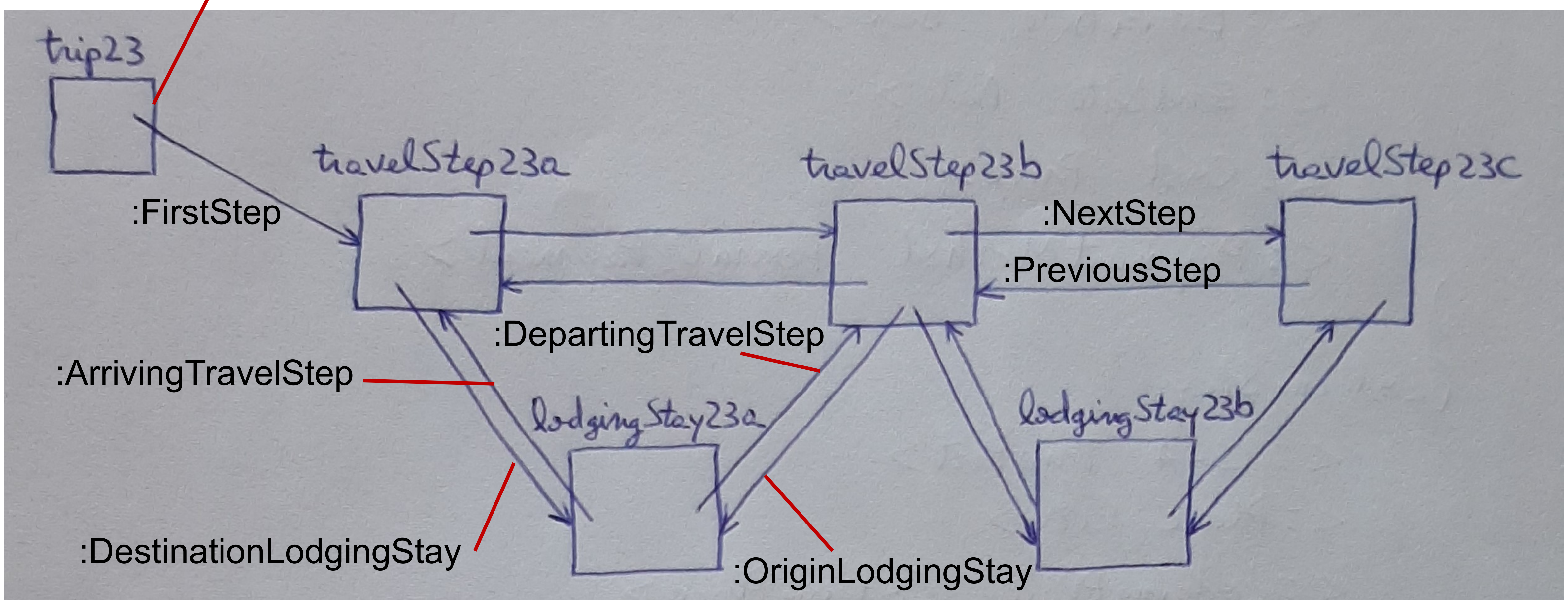
The constraints between slots are expressed by the attached IF-ADDED and IF-NEEDED procedures. The programmer decides whether reasoning is data-directed of goal-directed.

Frames – an example

(trip23
<:INSTANCE-OF Trip>
<:FirstStep travelStep23a>
<:Traveler davidF>
<:BeginDate 23/11/2019>
<:EndDate 25/11/2019>
<:TotalCost 3400RON>)

The generic frame

(Trip
<:FirstStep TravelStep>
<:Traveler Person>
<:BeginDate Date>
<:EndDate Date>
<:TotalCost Price>)



Frames – an example

The frames TravelStep and LodgingStay share some properties that we group in the more general frame TripPart

(TripPart
<:BeginDate Date>
<:EndDate Date>
<:Cost Price>
<:PaymentMethod FormOfPayment>)

or a default filler visaCard

(LodgingStay
<:IS-A TripPart>
<:Place City>
<:LodgingPlace LodgingPlace>
<:ArrivingTravelStep TravelStep>
<:DepartingTravelStep TravelStep>)

(TravelStep
<:IS-A TripPart>
<:Origin City>
<:Destination City>
<:OriginLodgingStay LodgingStay>
<:DestinationLodgingStay LodgingStay>
<:Means FormOfTransportation>
<:ArrivalTime Time>
<:DepartureTime Time>
<:NextStep TravelStep>
<:PreviousStep TravelStep>

Default fillers:
<:Means airplane>
<: PaymentMethod masterCard>

Frames – an example

Notations: if x is an individual frame and y is a slot, then xy refers to the filler of the slot in that frame;

SELF is a reference to the current frame

```
(TravelStep
<:Origin [IF-NEEDED
      {if no SELF:PreviousStep then otopeni;
        else SELF:PreviousStep:Destination;
}]>…
)
```

```
(TravelStep
<:PreviousStep [IF-ADDED
     {SELF:PreviousStep:NextStep←SELF;}
]>…)
```

```
(TravelStep
<:NextStep [IF-ADDED
 {if SELF:EndDate≠SELF:NextStep:BeginDate then
     {SELF:DestinationLodgingStay←
      SELF:NextStep:OriginLodgingStay←
           new LodgingStay;
           with :BeginDate=SELF:EndDate;
           with :EndDate=SELF:NextStep:BeginDate;
           with :ArrivingTravelStep=SELF;
           with :DepartingTravelStep=SELF:NextStep;
}}
]>…)
```

Frames – an example

```
(Trip
<:TotalCost [IF-NEEDED
    {result←0
     x←SELF:FirstStep;
     repeat
         if exists x:NextStep then
                 {result←result+c:Cost;
                  if exists x:DestinationLodgingStay then
                      {result←result+x:DestinationLodgingStay:Cost;}
                  x←x:NextStep;
                  }
            else return result+x:Cost;
    }
]>…)
```

```
(LodgingStay
<:Place [IF-NEEDED
{SELF:ArrivingTravelStep:Destination}
]>…)
```

Frames – an example

For a certain trip, called trip23, we create an individual frame and two instances of TravelStep:

```
(trip23
<:INSTANCE-OF Trip>
<:FirstStep travelStep23a>
)
```

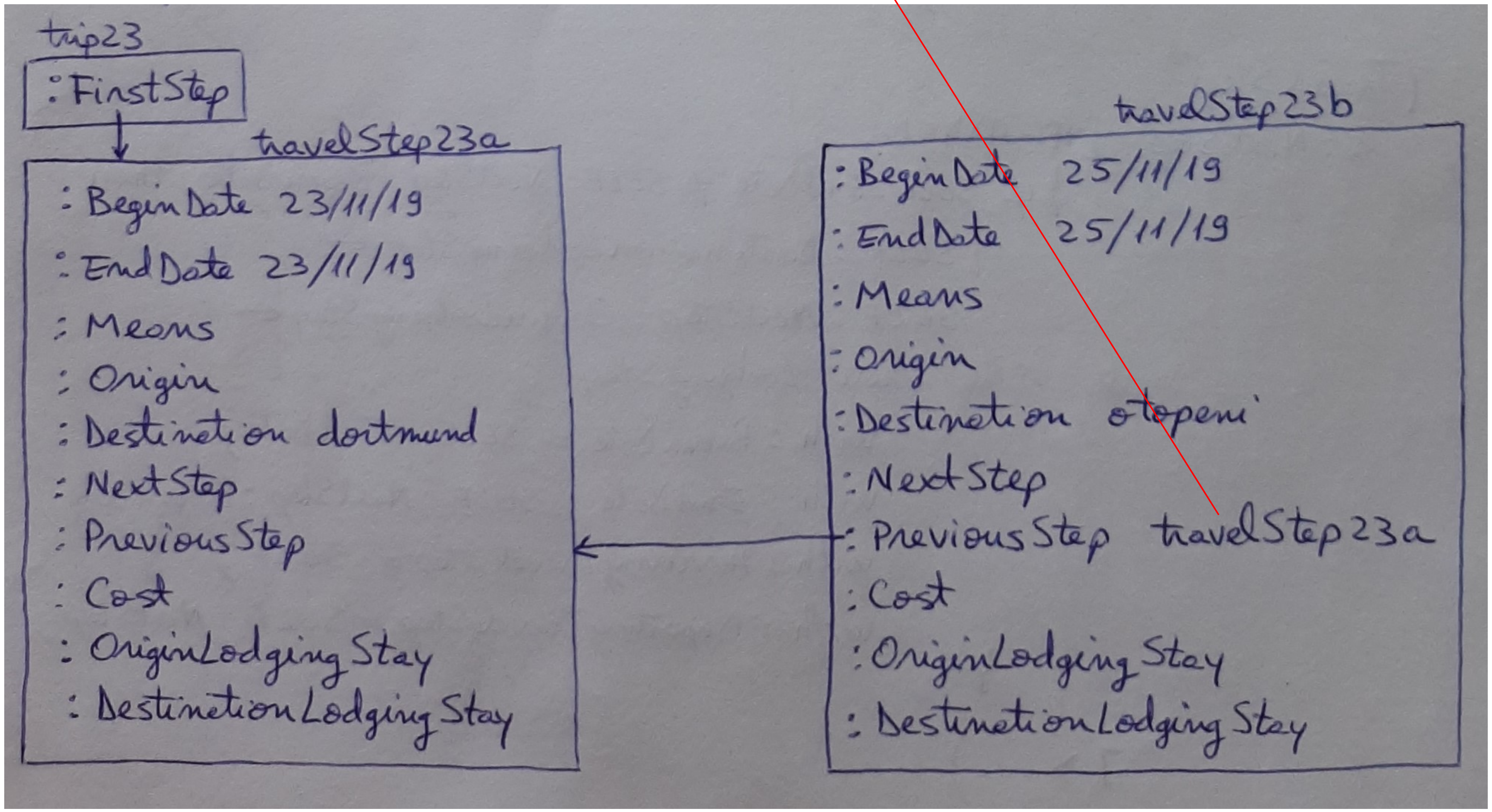
```
(travelStep23a
<:INSTANCE-OF TravelStep>
<:Destination dortmund>
<:BeginDate 23/11/2019>
<:EndDate 23/11/2019>
)
```

```
(travelStep23b
<:INSTANCE-OF TravelStep>
<:Destination otopeni>
<:BeginDate 25/11/2019>
<:EndDate 25/11/2019>
<:PreviousStep travelStep23a>
)
```

Frames – an example

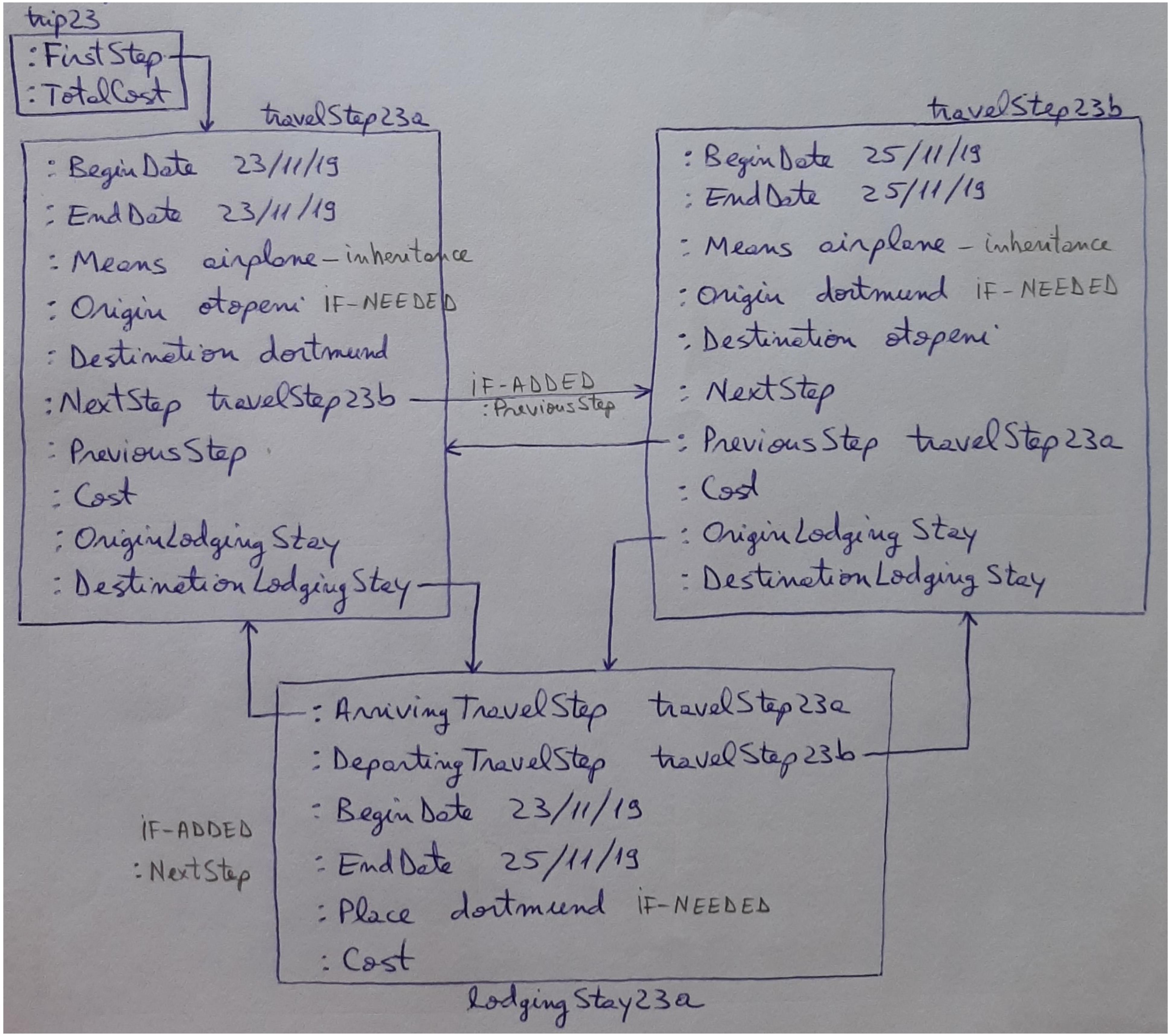
Initial trigger:

(TravelStep <:PreviousStep [IF-ADDED …]>…)



Frames – an example

The instance lodgingStay23a is created by the IF-ADDED procedure inherited by :NextStep in travelStep23a



Frames – summary

Good candidates for representation by frames are applications that have, in general, common stereotype structures that can be filled with details of particular situations

Facts are clustered around objects

Slots contain information of various types: simple values, references to other frames or procedures

Unfilled slots can be filled through inference

A representation in PROLOG can be found in the book of Ivan Bratko, p. 351-355 (2nd edition)

Frame languages have a significant overlap with object-oriented programming (OOP) languages

The main difference:

- Frame systems have a centralized, conventional control regime that works in a cycle: instantiate a frame, declare some slot fillers, inherit values, trigger procedures and then wait for the next input (i.e. instantiated frame)
- OOP systems tend to be more decentralized, where objects act as independent agents sending each other messages