Fundamentals of Artificial Intelligence

Laboratory

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Exercise 11.1

- On a table there are: a container with an unlimited supply of sweets and 100 boxes, each of which can contain at most 3 sweets and can be wrapped up in paper. A robotic arm with a gripper can: take a sweet from the container (if the gripper is empty); put a sweet in a box (if the gripper holds a sweet, the box can contain one more sweet, and the box is not wrapped); wrap up a box (if the gripper is empty). Initially the gripper is empty and the 100 boxes are empty and not wrapped. The goal is to have a box containing 2 sweets and wrapped up. However, the goal must not specify which of the boxes must be filled and wrapped up (the choice must be left to the planning algorithm).

Using PDDL:

a. Introduce a suitable set of constants and predicates, describing their intuitive meaning (try to keep the set of predicates to a minimum);

b. Represent the initial state and the goal of the planning problem (concerning the goal, read carefully the specifications above);

c. Specify a set of action schemas sufficient to solve the planning problem.

Exercise 10.1

a. Introduce a suitable set of constants and predicates

Predicates:

InBox(x,n)	box x contains n sweets
Wrapped(x)	x is wrapped
HoldsSweet	the gripper holds a sweet

Constants:

B1, ..., B100	the boxes
0, 1, 2, 3	number of sweets

Exercise 10.1

b. Represent the initial state and the goal of the planning problem

Initial state:
InBox(B1,0), ..., InBox(B100,0)

Goal:
InBox(x,2) ∧ Wrapped(x)

Exercise 11.1

c. Specify a set of action schemas sufficient to solve the planning problem.

// Pickup a sweet from the sweet container
Action(ACTION: pickUp(), PRECOND: ¬HoldsSweet,
EFFECT: HoldsSweet)

// Put first sweet into box x
Action(ACTION: put1(x), PRECOND: HoldsSweet ∧ InBox(x,0) ∧ ¬Wrapped(x),
EFFECT: InBox(x,1) ∧ ¬InBox(x,0) ∧ ¬HoldsSweet)

// Put second sweet into box x
Action(ACTION: put2(x), PRECOND: HoldsSweet ∧ InBox(x,1) ∧ ¬Wrapped(x),
EFFECT: InBox(x,2) ∧ ¬InBox(x,1) ∧ ¬HoldsSweet)

// Put third sweet into box x
Action(ACTION: put3(x), PRECOND: HoldsSweet ∧ InBox(x,2) ∧ ¬Wrapped(x),
EFFECT: InBox(x,3) ∧ ¬InBox(x,2) ∧ ¬HoldsSweet)

// Wrap up box x
Action(ACTION: wrap(x), PRECOND: (¬HoldsSweet ∧ ¬Wrapped(x))
EFFECT: Wrapped(x))

Exercise 11.2

- **Making a cup of tea**
  The Project work area is the worktop around a electric kettle in a kitchen. All non human Project resources are available in the kitchen and to start with let us make the Project Manager (David) do all the real work for a change. The Project tasks, durations, effort and task predecessors are listed in the table below.

PROJECT - Cup of Tea - Task List				
#	Description	Duration (secs)	Effort (secs)	Pre-decessor #
1	START at Kettle Area	0	0	None
2	Get Clean Mug from Cupboard, take to kettle area	15	15	1
3	Get Teabag from container, take to kettle area	10	10	1
4	Fill kettle with enough water and return to kettle area	20	20	1
5	Put teabag into Mug	5	5	2,3
6	Boil Kettle	180	2	4
7	Pour boiling water into Mug	5	5	5,6
8	Let tea brew in Mug	30	1	7
9	Get milk from Fridge and take to kettle area	20	20	1
10	Get spoon from Drawer and take to kettle area	10	10	1
11	Remove teabag with spoon and put in bin	10	10	10,8
12	Pour milk into Mug and return to Fridge	25	25	9,11
13	Rinse spoon, dry and return to drawer	20	20	11
14	FINISH at Kettle Area	0	0	13,12

Exercise 11.2

- **Questions:**

a. What task numbers are on the critical path for the basic network?
b. If there is no consideration of over allocated resources, what is the earliest finish time of your Project?
c. If you remove the over allocation of tasks to David, what is the earliest finish time of your Project?
d. If you bring in as many team-mates as you like to help David, reallocating some of the tasks to these folk (but nobody is over-allocated work), what is the earliest finish time of your Project now and how many people did you require?

Please consider that:

- Start date is 1 January 2015 at time 10:00
- There are no periods of non working to account for
- All tasks are carried out by one resource named David (to start with)

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3	Get Teabag from container, take to kettle area	10	10	1
4	Fill kettle with enough water and return to kettle area	20	20	1
5	Put teabag into Mug	5	5	2,3
6	Boil Kettle	180	2	4
7	Pour boiling water into Mug	5	5	5,6
8	Let tea brew in Mug	30	1	7
9	Get milk from Fridge and take to kettle area	20	20	1
10	Get spoon from Drawer and take to kettle area	10	10	1
11	Remove teabag with spoon and put in bin	10	10	10,8
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Exercise 11.2

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4	Fill kettle with enough water and return to kettle area	20	20	1
5	Put teabag into Mug	5	5	2,3
6	Boil Kettle	180	2	4
7	Pour boiling water into Mug	5	5	5,6
8	Let tea brew in Mug	30	1	7
9	Get milk from Fridge and take to kettle area	20	20	1
10	Get spoon from Drawer and take to kettle area	10	10	1
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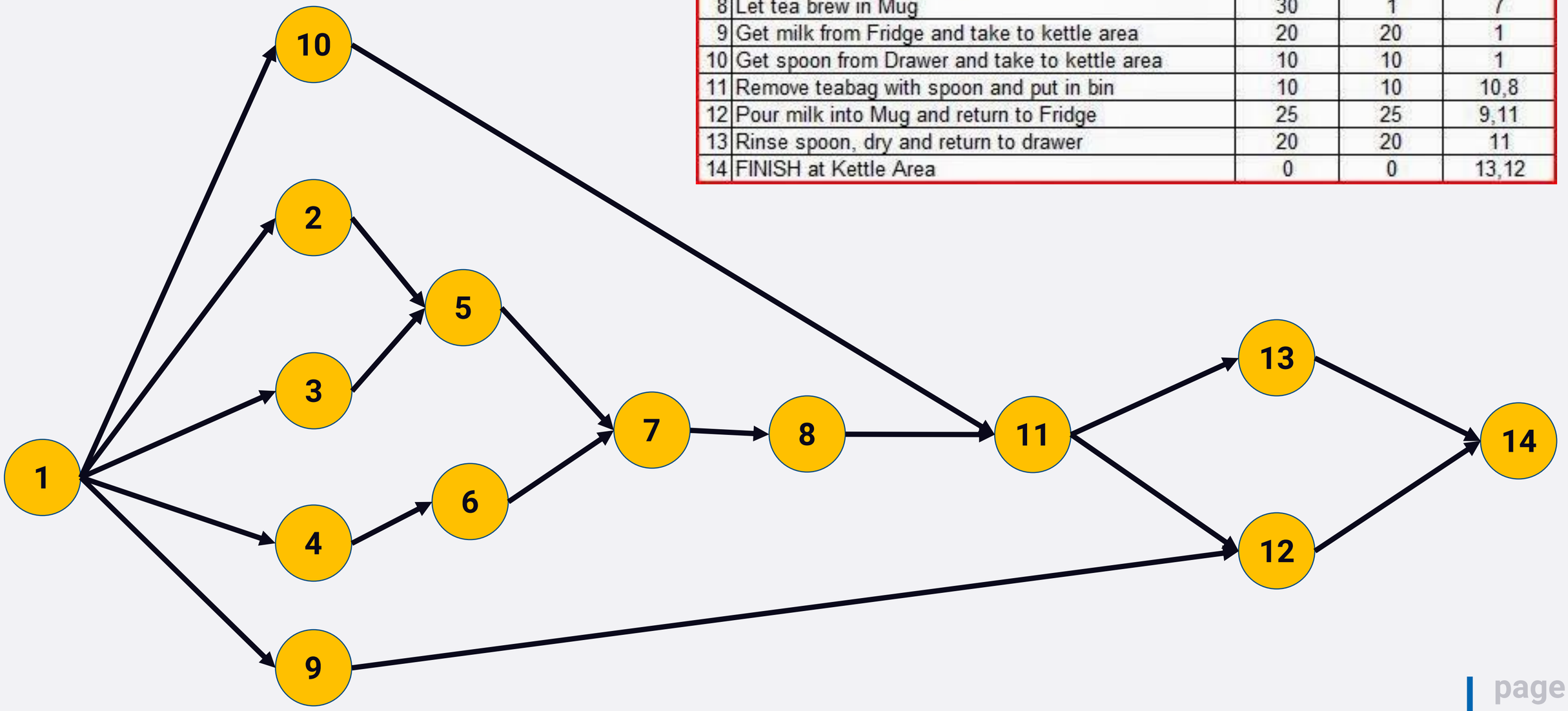

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Task Name	Dur	Effort	Crit	Start	Finish	Predeces
START	0 days	0 mins	Yes	01/01/15 10:00	01/01/15 10:00	
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Boil Kettle	180 mins	2 mins	Yes	01/01/15 10:20	01/01/15 13:20	4
Pour boiling water into Mug	5 mins	5 mins	Yes	01/01/15 13:20	01/01/15 13:25	5,6
Let tea brew in Mug	30 mins	1 min	Yes	01/01/15 13:25	01/01/15 13:55	7
Get milk from Fridge and take to kettle area	20 mins	20 mins	No	01/01/15 10:00	01/01/15 10:20	1
Get spoon from Drawer and take to kettle area	10 mins	10 mins	No	01/01/15 10:00	01/01/15 10:10	1
Remove teabag with spoon and put in bin	10 mins	10 mins	Yes	01/01/15 13:55	01/01/15 14:05	10,8
Pour milk into Mug and return to Fridge	25 mins	25 mins	Yes	01/01/15 14:05	01/01/15 14:30	9,11
Rinse spoon, dry and return to drawer	20 mins	20 mins	No	01/01/15 14:05	01/01/15 14:25	11
FINISH	0 days	0 mins	Yes	01/01/15 14:30	01/01/15 14:30	13,12

Exercise 11.2

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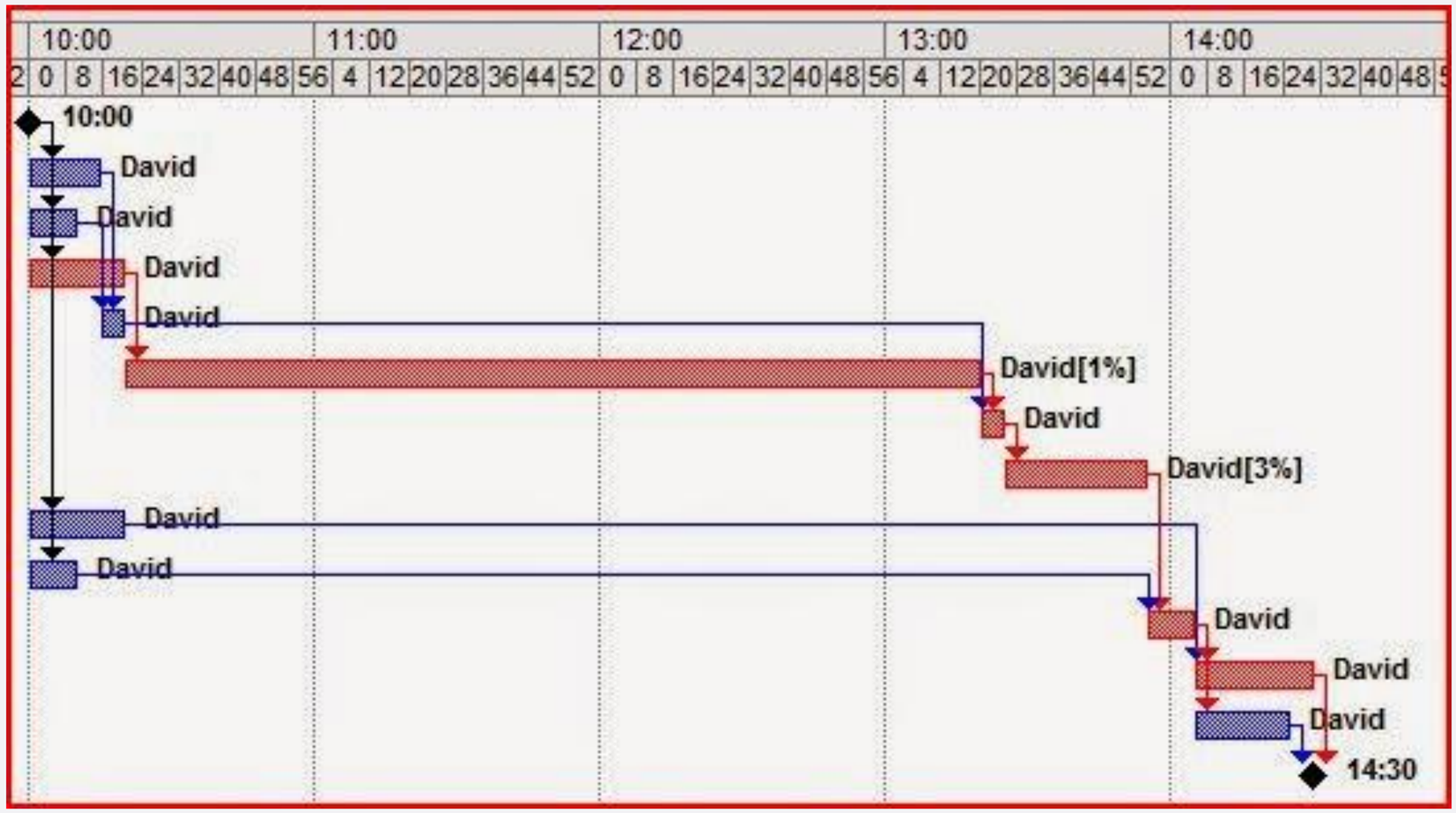

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Get Teabag from container, take to kettle area	10 mins	10 mins	No	01/01/15 10:00	01/01/15 10:10	1
Fill kettle with enough water and return to kettle area	20 mins	20 mins	Yes	01/01/15 10:00	01/01/15 10:20	1
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FINISH	0 days	0 mins	Yes	01/01/15 14:30	01/01/15 14:30	13,12

Exercise 11.2

- **Answers:**

a. What task numbers are on the critical path for the basic network?

   1,14 (start and end milestones) and in terms of real tasks, 4, 6, 7, 8, 11, 12

b. If there is no consideration of over allocated resources, what is the earliest finish time of your Project?

   14:30

c. If you remove the over allocation of tasks to David, what is the earliest finish time of your Project?

   14:50

d. If you bring in as many team-mates as you like to help David, reallocating some of the tasks to these folk (but nobody is over-allocated work), what is the earliest finish time of your Project now and how many people did you require?

   14:30 with one extra person

Exercise 11.3

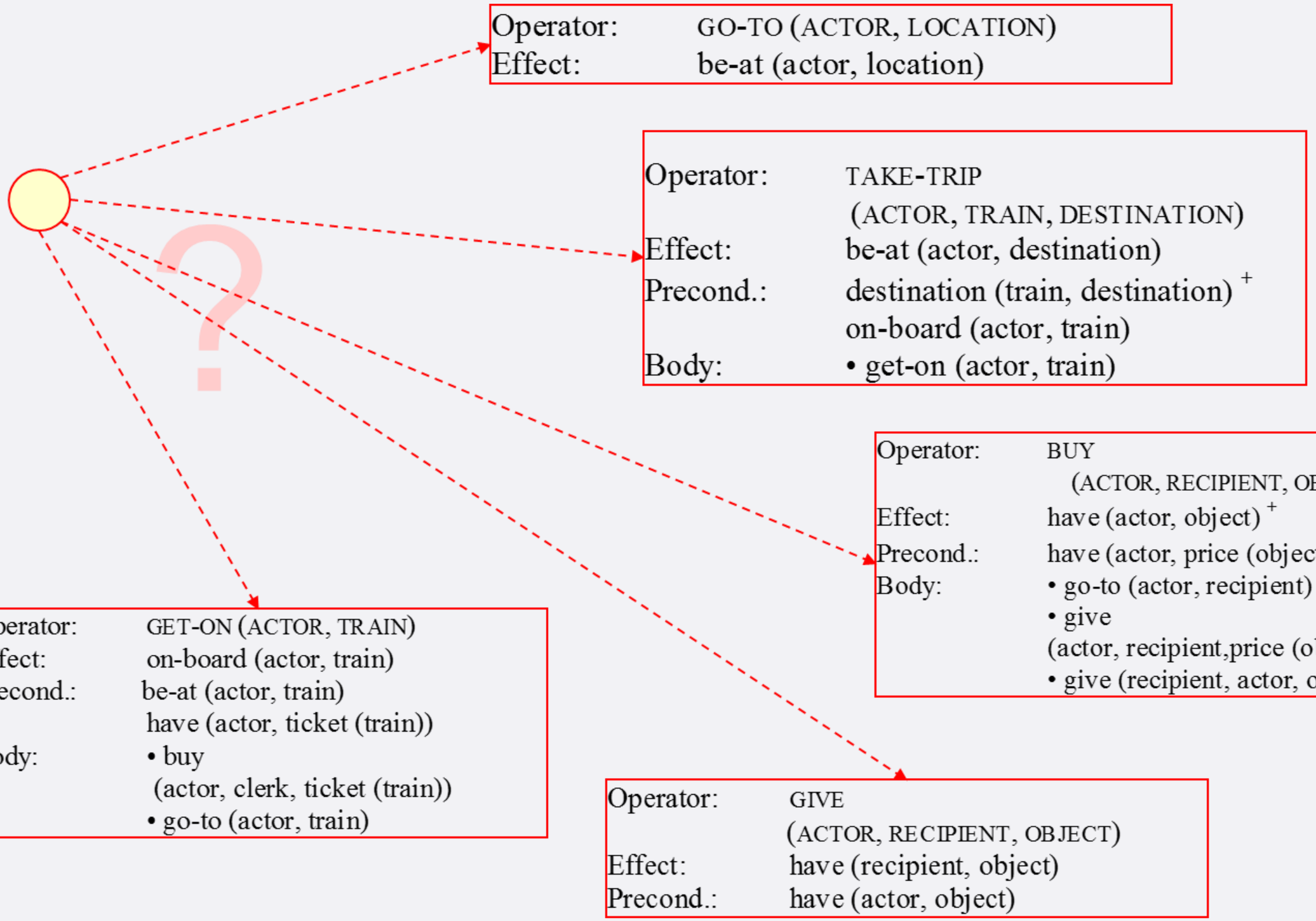
- **Hierarchical Planning - Task:**
  Ed wants to be in New York

- **Formalization as a plan goal:**
  be-at (Ed, New York)

- **The algorithm: Top-down hierarchical planning**
  - Search our library of plan operators for ways of achieving the goal
  - For an operator to be usable, the preconditions much match the ‘state of the world’
  - For an operator to be useful, the effect must leave us nearer to achieving our goal than we were before!

Exercise 11.3

- **Our PLAN OPERATORS**



Exercise 11.3

be-at (Ed, New York)

Operator: GET-ON (ACTOR, TRAIN)

Effect: on-board (actor, train)

Precond.: be-at (actor, train)
have (actor, ticket (train))

Body:
- buy (actor, clerk, ticket (train))
- go-to (actor, train)

Exercise 11.3

be-at (Ed, New York)

Operator: TAKE-TRIP (ACTOR, TRAIN, DESTINATION)

Effect: be-at (actor, destination)

Precond.: destination (train, destination) $^{+}$
on-board (actor, train)

Body: • get-on (actor, train)

Exercise 11.3

be-at (Ed, New York)

Operator: GO-TO (ACTOR, LOCATION)

Effect: be-at (actor, location)

Exercise 11.3

be-at (Ed, New York)

Operator: BUY (ACTOR, RECIPIENT, OBJECT)

Effect: have (actor, object) $^{+}$

Precond.: have (actor, price (object)) $^{+}$

Body:
- go-to (actor, recipient)
- give (actor, recipient,price (object))
- give (recipient, actor, object)

Exercise 11.3

be-at (Ed, New York)

Operator:	GIVE (ACTOR, RECIPIENT, OBJECT)
Effect:	have (recipient, object)
Precond.:	have (actor, object)

Exercise 11.3

Do we have a plan operator with a useful effect?

be-at (Ed, New York)

Exercise 11.3

- **Our PLAN OPERATORS**

cost?
time?

Operator: GO-TO (ACTOR, LOCATION)
Effect: be-at (actor, location)

Operator: TAKE-TRIP
(ACTOR, TRAIN, DESTINATION)
Effect: be-at (actor, destination)
Precond.: destination (train, destination) +
on-board (actor, train)
Body: • get-on (actor, train)

Operator: GET-ON (ACTOR, TRAIN)
Effect: on-board (actor, train)
Precond.: be-at (actor, train)
have (actor, ticket (train))
Body: • buy
(actor, clerk, ticket (train))
• go-to (actor, train)

Operator: GIVE
(ACTOR, RECIPIENT, OBJECT)
Effect: have (recipient, object)
Precond.: have (actor, object)

Operator: BUY
(ACTOR, RECIPIENT, OBJECT)
Effect: have (actor, object) +
Precond.: have (actor, price (object)) +
Body: • go-to (actor, recipient)
• give
(actor, recipient, price (object))
• give (recipient, actor, object)

Exercise 11.3

This one looks promising, the planning process decides to take a closer look…

Operator:	TAKE-TRIP (ACTOR, TRAIN, DESTINATION)
Effect:	be-at (actor, destination)
Precond.:	destination (train, destination) $^{+}$
	on-board (actor, train)
Body:	• get-on (actor, train)

Exercise 11.3

Task goal: be-at (Ed, NY)

Operator:	TAKE-TRIP (ACTOR, TRAIN, DESTINATION)
Effect:	be-at (actor, destination)
Precond.:	destination (train, destination) $^{+}$
	on-board (actor, train)
Body:	• get-on (actor, train)

Matching or 'unification'

be-at (Ed, NY)

be-at (actor, destination)

Exercise 11.3

TAKE-TRIP (Ed, train, NY)
Effect: BE-AT (Ed, NY)
Precond. DESTINATION (train, NY)
ON-BOARD (Ed, train)

Operator:	TAKE-TRIP (ACTOR, TRAIN, DESTINATION)
Effect:	be-at (actor, destination)
Precond.:	destination (train, destination) + on-board (actor, train)
Body:	• get-on (actor, train)

Exercise 11.3

TAKE-TRIP (Ed, train, NY)
Effect: BE-AT (Ed, NY)
Precond. DESTINATION (train, NY)
ON-BOARD (Ed, train)

Operator: TAKE-TRIP
(ACTOR, TRAIN, DESTINATION)
Effect: be-at (actor, destination)
Precond.: destination (train, destination) +
on-board (actor, train)
Body: • get-on (actor, train)

Exercise 11.3

TAKE-TRIP (Ed, train, NY)
Effect: BE-AT (Ed, NY)
Precond. DESTINATION (train, NY)
ON-BOARD (Ed, train)

Operator: TAKE-TRIP
(ACTOR, TRAIN, DESTINATION)
Effect: be-at (actor, destination)
Precond.: destination (train, destination) +
on-board (actor, train)
Body: • get-on (actor, train)

ACTOR = Ed **TRAIN=?train** **DESTINATION= NY**

Exercise 11.3

- **TESTING PHASE**

- Do the preconditions hold? If not, we have to make them hold by planning further before we can carry out the action and get the desired effect

- When the preconditions hold, we can achieve the effect by adding the actions in the body into our plan. This is the hierarchical expansion of the plan tree.

Exercise 11.3

Do the preconditions hold?

ACTOR = Ed	TRAIN=?train	DESTINATION= NY
Operator:	TAKE-TRIP (ACTOR, TRAIN, DESTINATION)	
Effect:	be-at (actor, destination)	
Precond.:	destination (train, destination) on-board (actor, train)	
Body:	• get-on (actor, train)	

Destination (?train, NY)
On-board (Ed, ?train)

Exercise 11.3

The preconditions do not yet match the world unfortunately…

WORLD

Be-at
(Ed, Washington)

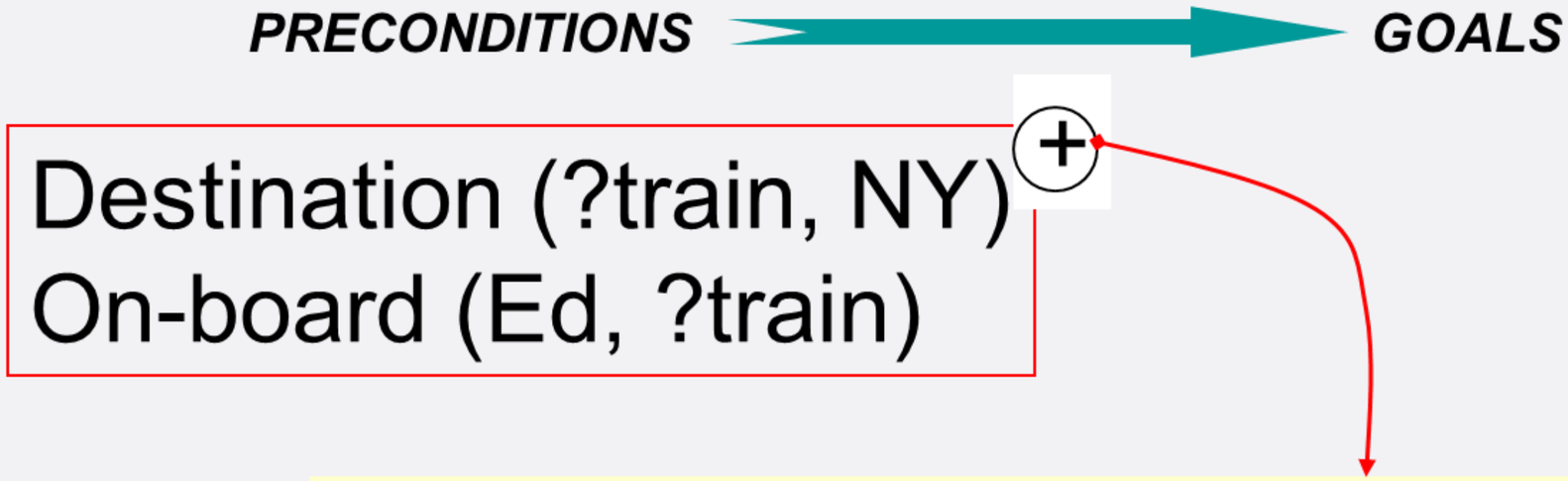
PRECONDITIONS

Destination (?train, NY)
On-board (Ed, ?train)

So, can we plan some actions that will take the world to be nearer to how we want it?

Exercise 11.3

We set up some new goals (called ‘posting’) and see if we can plan for them to be achieved…



- ***Lets us assume that there are lots of trains to NY from Washington, so the first goal can be filled in directly (‘be satisfied’) by looking in a database, e.g.:***
  - destination (9am-train, NY)
  - destination (10am-train ,NY)
  - destination (11am-train, NY).

Exercise 11.3

We set up some new goals (called ‘posting’) and see if we can plan for them to be achieved…

PRECONDITIONS → ***GOALS***

Destination (?train, NY)
On-board (Ed, ?train)

- ***The second goal takes more work. We have to look in our plan library for operators with an effect that is relevant for:***
  - On-board (Ed, 10am-train)

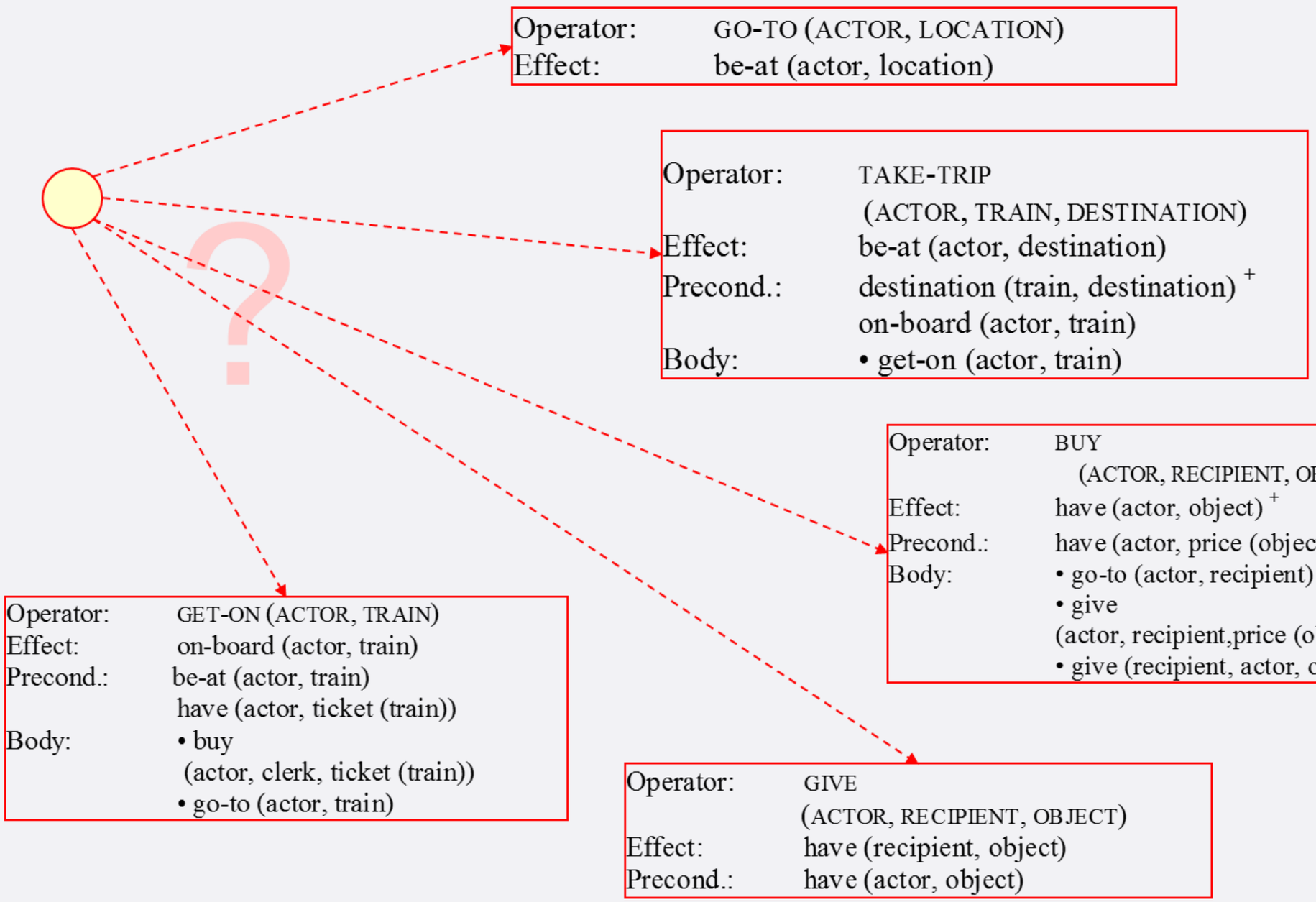
Exercise 11.3

Do we have a plan operator with a useful effect?

On-board (Ed, 10am-train)

Exercise 11.3

On-board (Ed, 10am-train)



Exercise 11.3

On-board (Ed, 10am-train)

Operator:	TAKE-TRIP (ACTOR, TRAIN, DESTINATION)
Effect:	be-at (actor, destination)
Precond.:	destination (train, destination) $^{+}$
	on-board (actor, train)
Body:	• get-on (actor, train)

Exercise 11.3

On-board (Ed, 10am-train)

Operator:	GIVE (ACTOR, RECIPIENT, OBJECT)
Effect:	have (recipient, object)
Precond.:	have (actor, object)

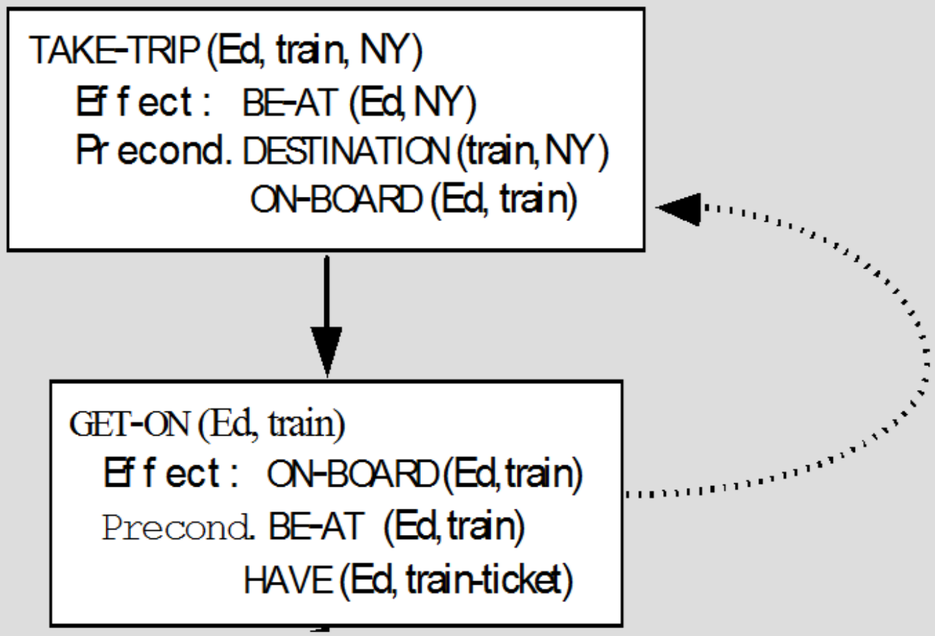
Exercise 11.3

On-board (Ed, 10am-train)

Operator:	GET-ON (ACTOR, TRAIN)
Effect:	on-board (actor, train)
Precond.:	be-at (actor, train) have (actor, ticket (train))
Body:	• buy (actor, clerk, ticket (train)) • go-to (actor, train)

This one looks promising, the planning process decides to take a closer look…

Exercise 11.3



Operator:	GET-ON (ACTOR, TRAIN)
Effect:	on-board (actor, train)
Precond.:	be-at (actor, train)
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Body:	• buy
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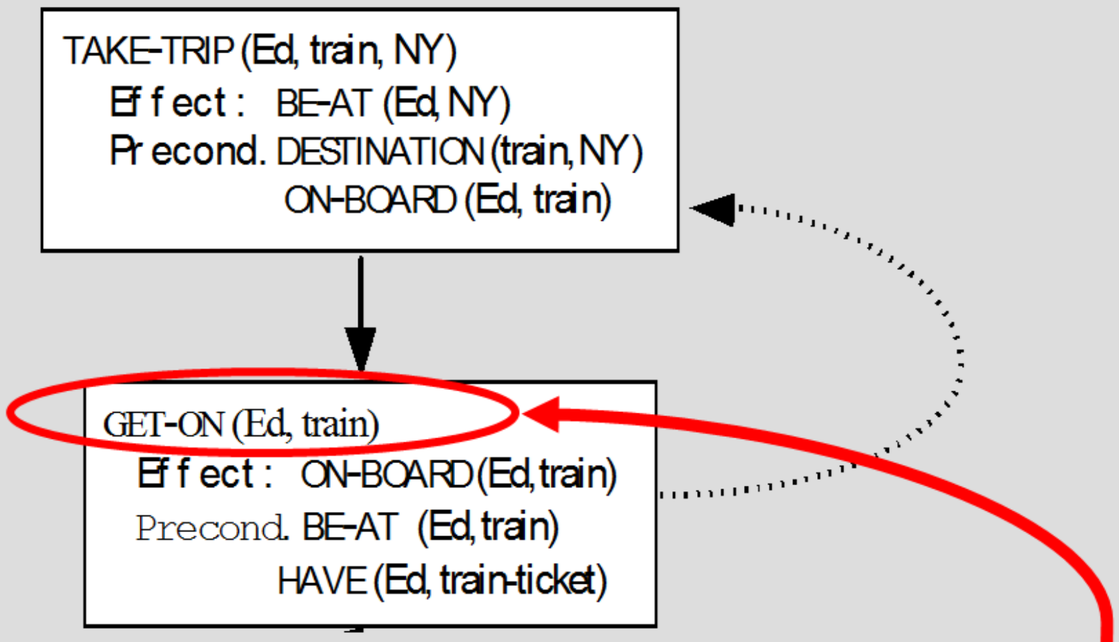
	• go-to (actor, train)

Exercise 11.3



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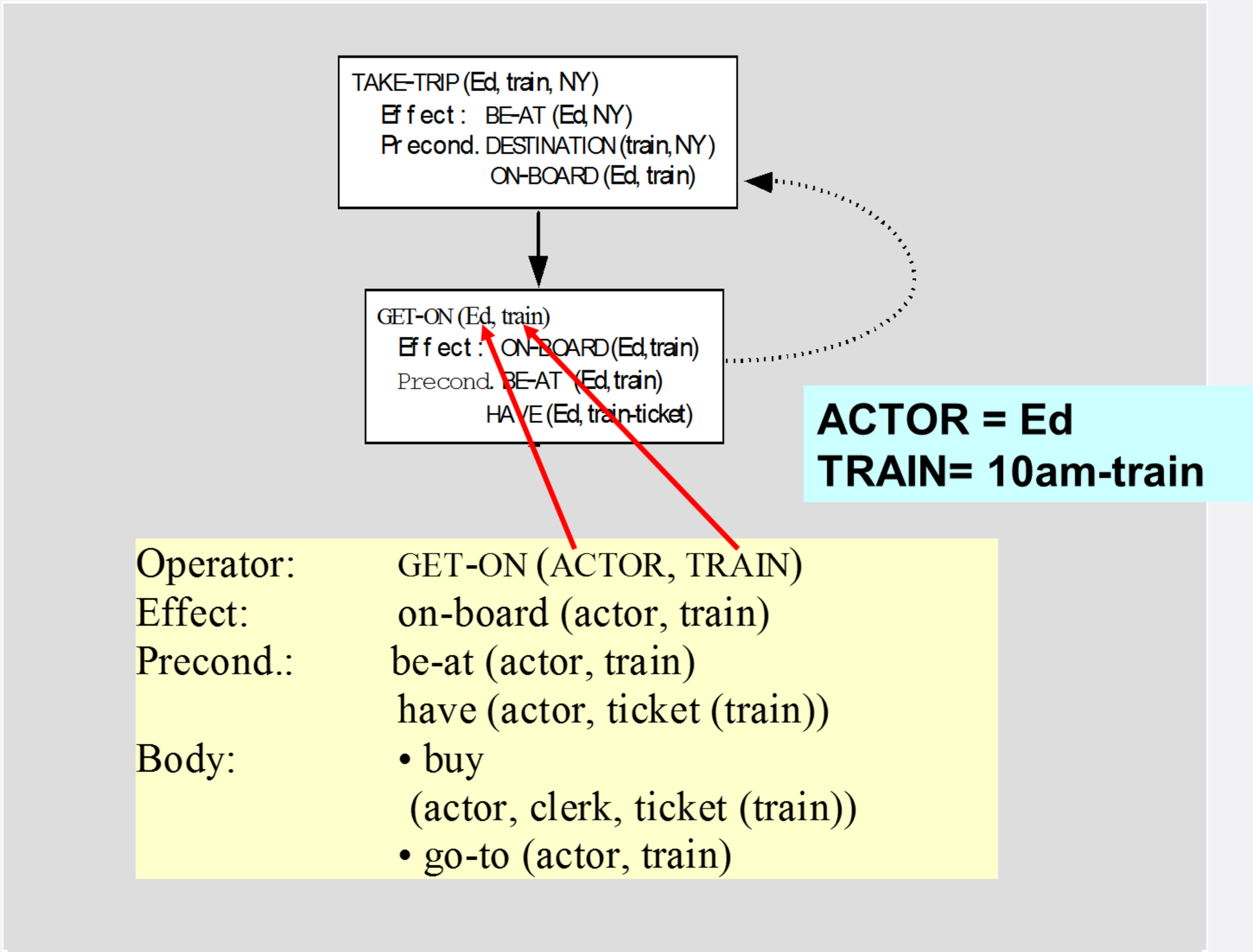
Exercise 11.3



Operator: GET-ON (ACTOR, TRAIN)
Effect: on-board (actor, train)
Precond.: be-at (actor, train)
have (actor, ticket (train))
Body: • buy
(actor, clerk, ticket (train))
• go-to (actor, train)

Exercise 11.3

Do the preconditions hold?

ACTOR = Ed	TRAIN=10-am-train
Operator:	GET-ON (ACTOR, TRAIN)
Effect:	on-board (actor, train)
Precond.:	be-at (actor, train) have (actor, ticket (train))
Body:	• buy (actor, clerk, ticket (train)) • go-to (actor, train)

Be-at (Ed, 10am-train)
Have (Ed, ticket (10am-train))

Exercise 11.3

The preconditions do not yet match the world unfortunately…

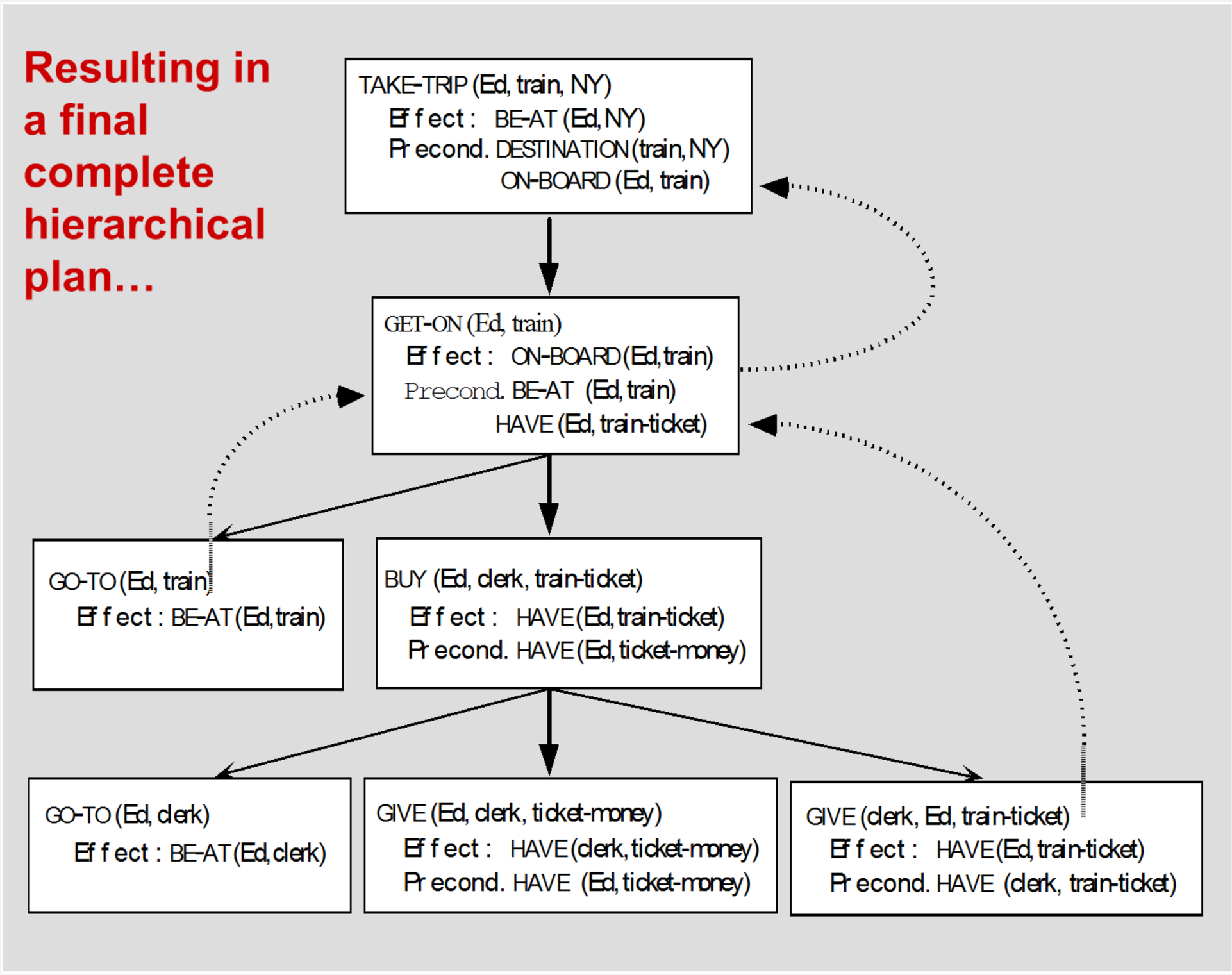
WORLD	***PRECONDITIONS***
Be-at (Ed, Washington)	Be-at (Ed, 10am-train) Have (Ed, ticket (10am-train))

So, can we plan some actions that will take the world to be nearer to how we want it?

Further planning as above

Exercise 11.3

Resulting in a final complete hierarchical plan…



Exercise 11.4 - Homework

- Consider a simple case of resource allocation that contains 12 uninterruptible tasks, each with fixed duration and demand. These tasks need to be scheduled on a single renewable resource that has a capacity of eight units.

Task	Duration	Demand	Successors
1	1	4	4
2	2	2	5
3	2	3	
4	6	3	
5	3	2	
6	6	3	12
7	1	1	8, 9, 10
8	3	2	11
9	3	2	12
10	4	1	12
11	2	2	12
12	4	2	