Hierarchical Task Network (HTN) Planning

Section 11.2

Outline

- Example
- Primitive vs. non-primitive operators
- HTN planning algorithm
- Practical planners

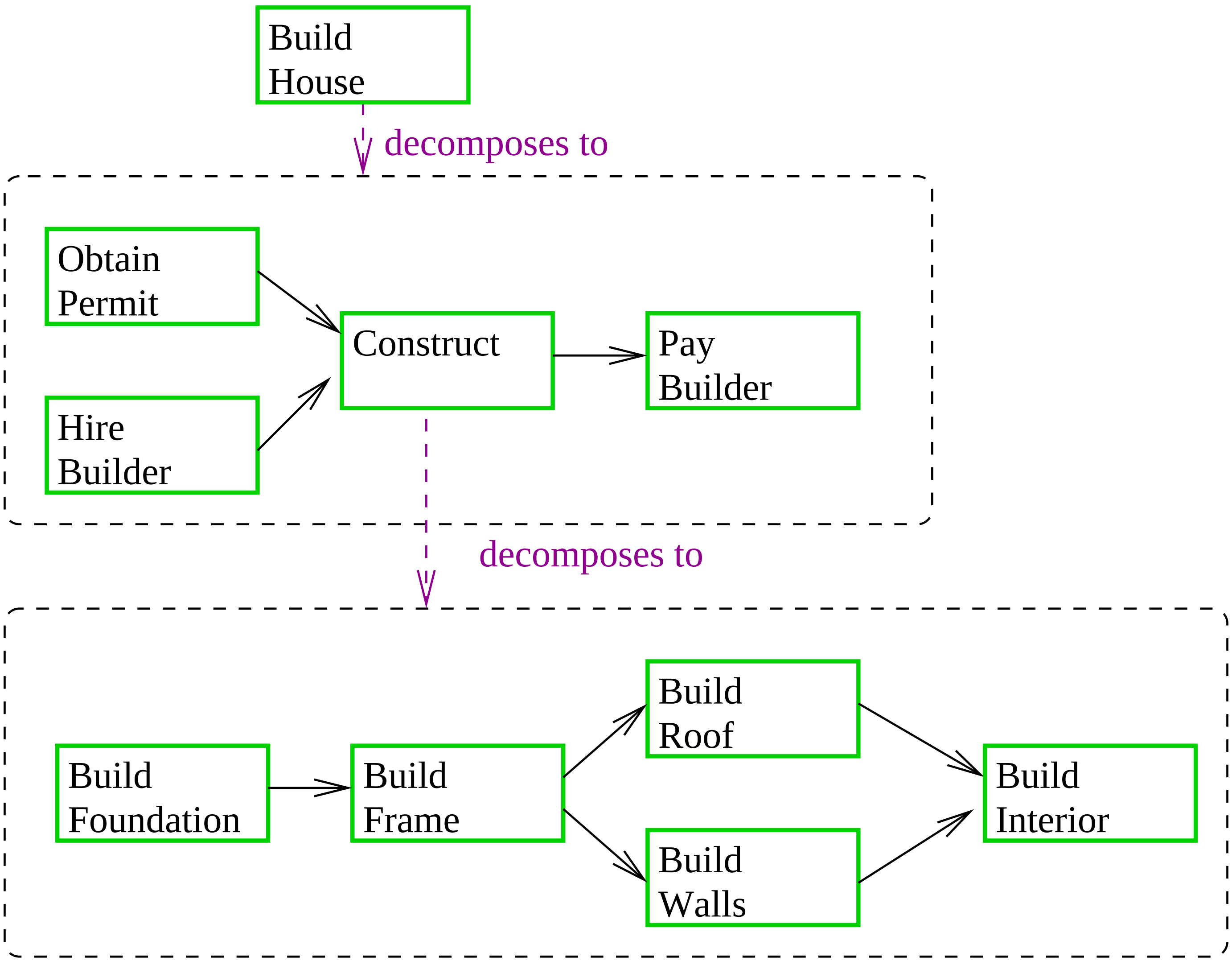
Additional references used for the slides:

desJardins, M. (2001). CMSC 671 slides.
www.cs.umbc.edu

Hierarchical Task Network (HTN) planning

- Idea: Many tasks in real life already have a built-in hierarchical structure
- For example: a computational task, a military mission, an administrative task
- It would be a waste of time to construct plans from individual operators. Using the built-in hierarchy help escape from exponential explosion
- Running example: the activity of building a house consists of obtaining the necessary permits, finding a builder, constructing the exterior/interior, ...
- HTN approach: use *abstract operators* as well as *primitive operators* during plan generation.

Building a house



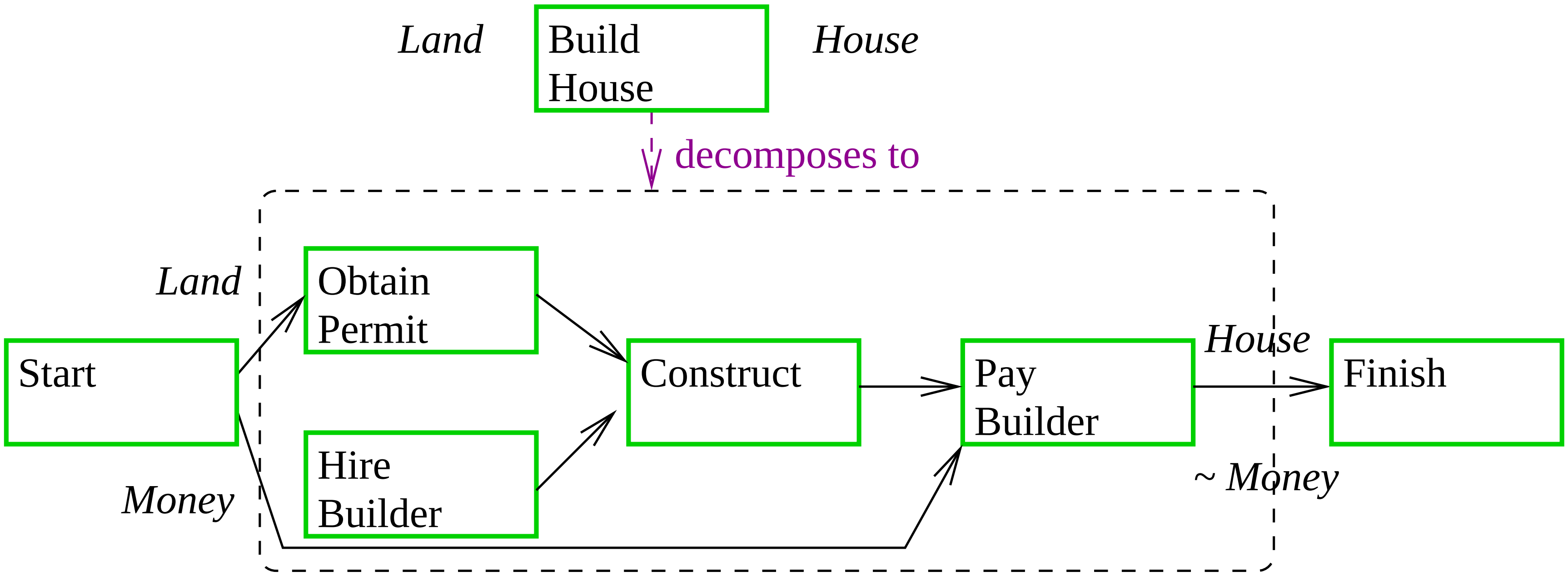
Hierarchical decomposition

- HTN is suitable for domains where tasks are naturally organized in a hierarchy.
- Uses abstract operators to start a plan.
- Use partial-order planning techniques and *action decomposition* to come up with the final plan
- The final plan contains only *primitive* operators.
- What is to be considered primitive is subjective: what an agent considers as primitive can be another agent's plans.

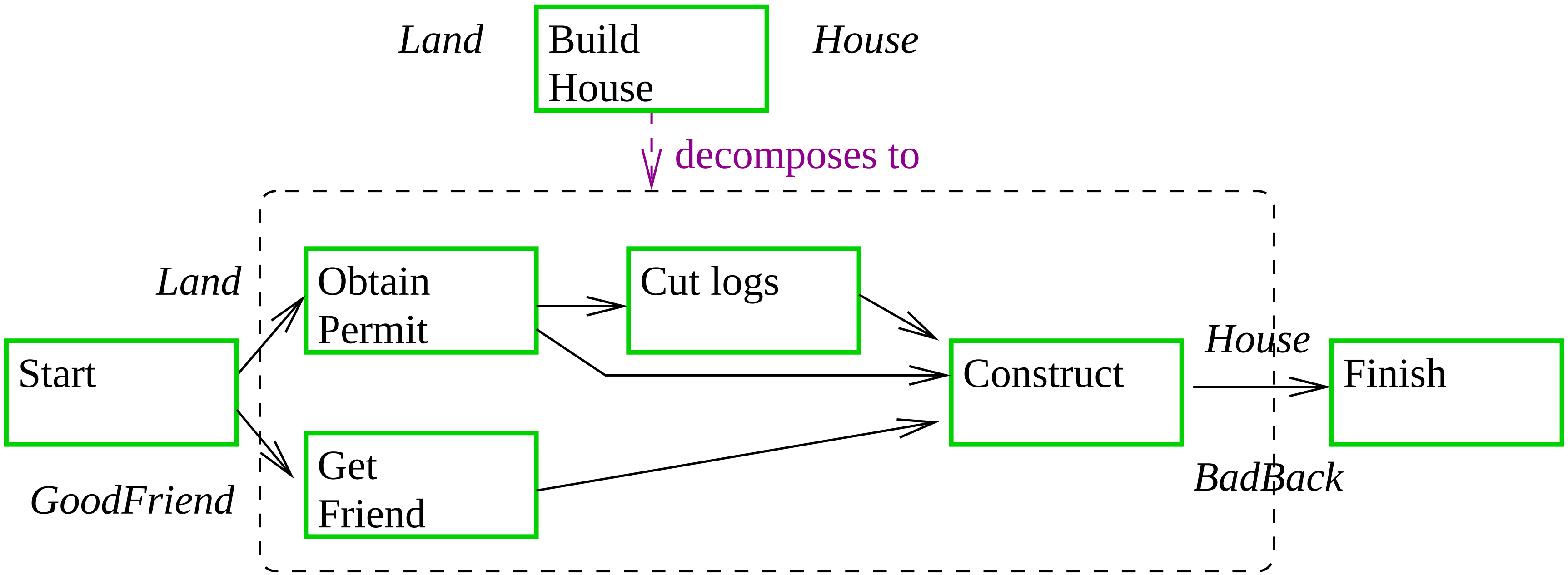
Representing action decompositions

- A *plan library* contains both primitive and non-primitive actions.
- Non-primitive actions have *external preconditions*, as well as *external effects*.
- Sometimes useful to distinguish between *primary effects* and *secondary effects*.

Building a house with causal links



Another way of building a house



Example action descriptions

$Action(BuyLand, \textsc{Precond}: Money, \textsc{Effect}: \mathrm{Land} \land \neg\, Money)$
$Action(GetLoan, \textsc{Precond}: GoodCredit, \textsc{Effect}: \mathrm{Money} \land Mortgage)$
$Action(BuildHouse, \textsc{Precond}: Land, \textsc{Effect}: House)$

$Action(GetPermit, \textsc{Precond}: Land, \textsc{Effect}: Permit)$
$Action(HireBuilder, \textsc{Effect}: Contract)$
$Action(Construct, \textsc{Precond}: Permit \land Contract,$
$\quad \textsc{Effect}: HouseBuilt \land \neg\, Permit)$
$Action(PayBuilder, \textsc{Precond}: Money \land HouseBuilt,$
$\quad \textsc{Effect}: \neg\, Money \land House \land \neg\, Contract)$

Example action descriptions

Decompose(*BuildHouse*,
Plan(STEPS:{S_1: *GetPermit*, S_2: *HireBuilder*,
S_3: *Construction*, S_4: *PayBuilder*,}
ORDERINGS: { $Start \prec S_1 \prec S_2 \prec S_3 \prec S_4 \prec Finish$,
$Start \prec S_2 \prec S_3$ },
LINKS: { $Start \xrightarrow{Land} S_1$, $Start \xrightarrow{Money} S_4$,
$S_1 \xrightarrow{Permit} S_3$, $S_2 \xrightarrow{Contract} S_3$, $S_3 \xrightarrow{HouseBuilt} S_4$,
$S_4 \xrightarrow{House} Finish$, $S_4 \xrightarrow{\neg Money} Finish$}))

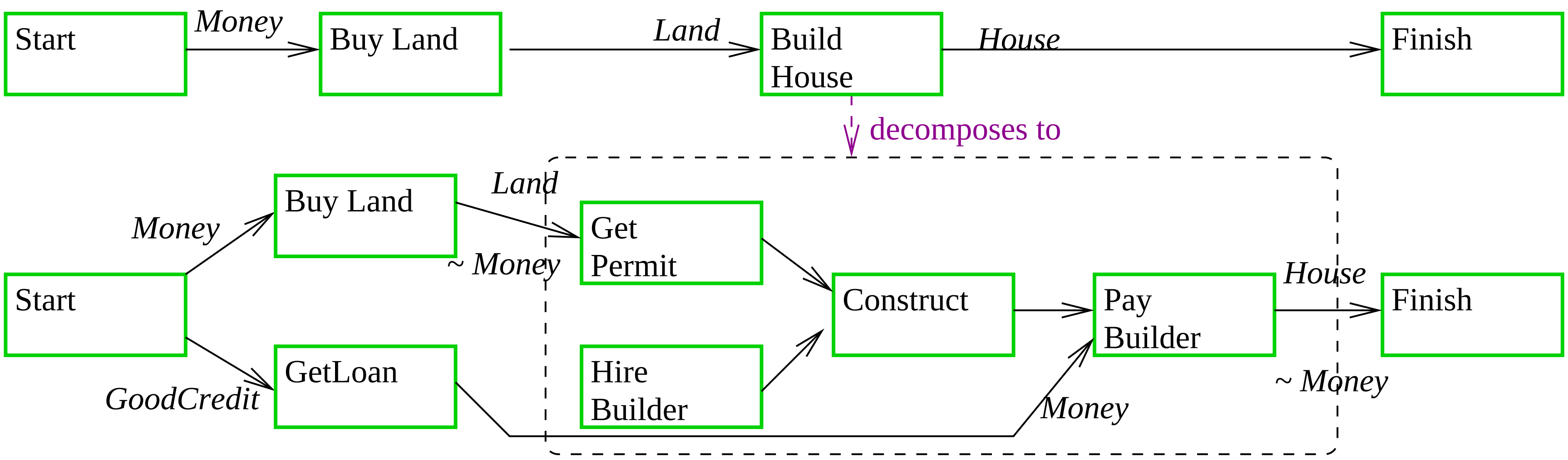
Correctness

- A decomposition should be a *correct* implementation of the action.
- A plan d implements an action a correctly if d is a complete and consistent partial-order plan for the problem of achieving the effects of a given the preconditions of a (result of a **sound** POP).
- The plan library contains several decompositions for any high-level action.
- Each decomposition might have different preconditions and effects. The preconditions of the high-level action should be the **intersection** of the preconditions of the decompositions (similarly for the external effects.)

Information hiding

- The high-level description hides all the *internal effects* of decompositions (e.g., $Permit$ and $Contract$).
- It also hides the duration the internal preconditions and effects hold.
- Advantage: reduces complexity by hiding details
- Disadvantage: conflicts are hidden too

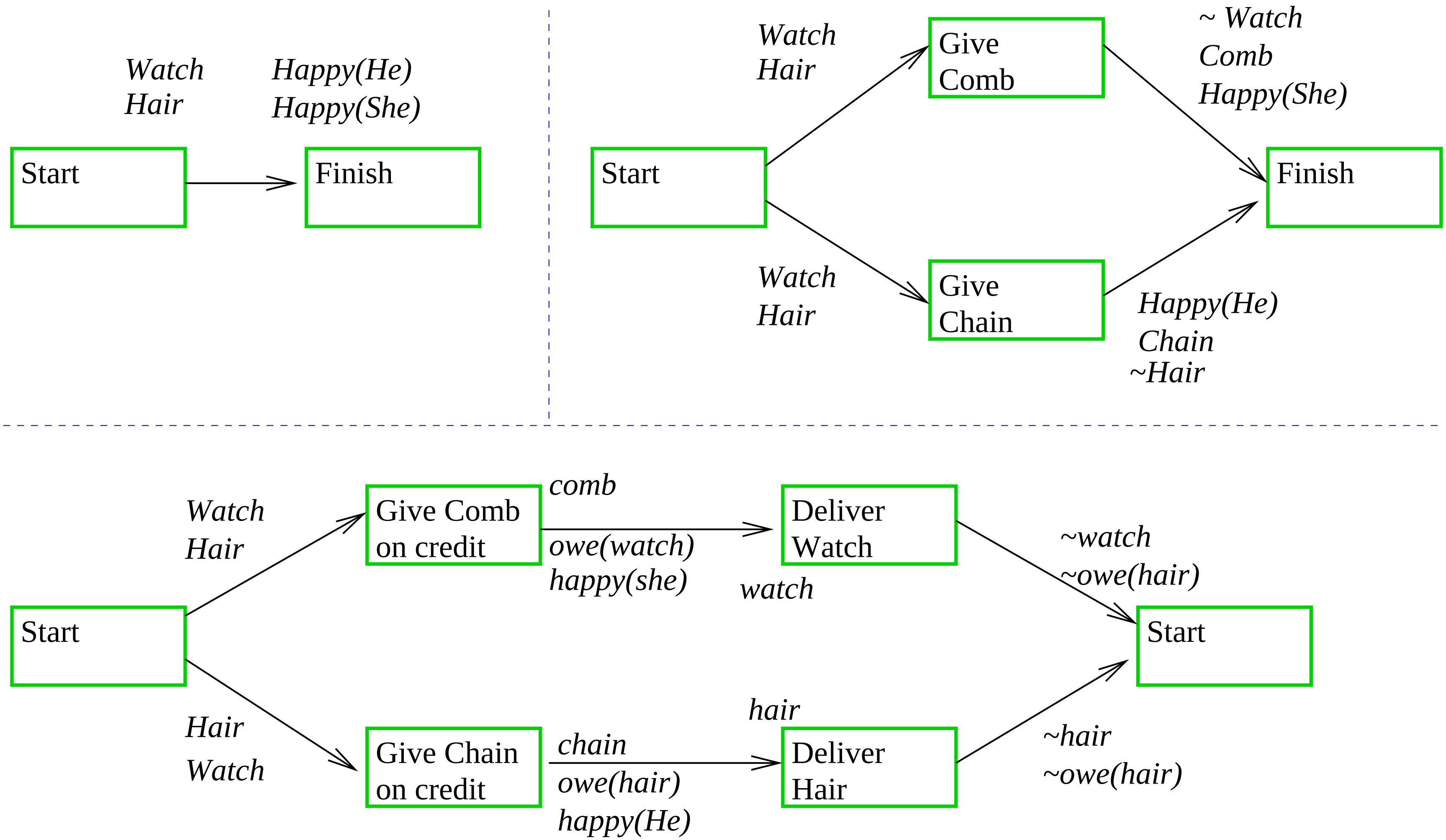
Example


Start
Money
Buy Land
Land
Build House
House
Finish
decomposes to
Buy Land
Land
Money
Get Permit
~ Money
Start
Construct
Pay Builder
House
Finish
GetLoan
GoodCredit
Hire Builder
~ Money
Money

For each decomposition d of an action a

- Remove the high level action, and insert/reuse actions for each action in d.
  reuse $\longrightarrow$ *subtask sharing*
- Merge the ordering constraints (If there is an ordering constraint of the form $B \prec a$, should every step of d come after B?)
- Merge the causal links

Action ordering



HTN planners

- Most industrial strength planners are HTN based.
- O-PLAN combines HTN planning with scheduling to develop production plans for Hitachi.
- SIPE-2 is an HTN planner with many advanced features
- SHOP is an HTN planner developed at the University of Maryland. It can deal with action durations.

The features of SIPE-2

- Plan critics
- Resource reasoning
- Constraint reasoning (complex numerical or symbolic variable and state constraints)
- Interleaved planning and execution
- Interactive plan development
- Sophisticated truth criterion
- Conditional effects
- Parallel interactions in partially ordered plans
- Replanning if failures occur during execution

An operator with constraints

```
OPERATOR decompose
PURPOSE: Construction
CONSTRAINTS:
  Length (Frame) <= Length (Foundation),
  Strength (Foundation) > Wt(Frame) + Wt(Roof)
    + Wt(Walls) + Wt(Interior) + Wt(Contents)
PLOT:   Build (Foundation)
  Build (Frame)
  PARALLEL
    Build (Roof)
    Build (Walls)
  END PARALLEL
  Build (Interior)
```

More on SIPE-2

- Russell & Norvig explicitly represent causal links; these can also be computed dynamically by using a model of preconditions and effects (this is what SIPE-2 does)
- Dynamically computing causal links means that actions from one operator can safely be interleaved with other operators, and subactions can safely be removed or replaced during plan repair
- Russell & Norvig's representation only includes variable bindings, but more generally we can introduce a wide array of variable constraints

Truth Criterion

- Determining whether a formula is true at a particular point in a partially ordered plan is, in the general case, NP-hard
- Intuition: there are exponentially many ways to linearize a partially ordered plan
- In the worst case, if there are N actions unordered with respect to each other, there are N! linearizations

Truth Criterion

- Ensuring soundness of the truth criterion requires checking the formula under all possible linearizations
- Use heuristic methods instead to make planning feasible
- Check later to be sure no constraints have been violated

Truth Criterion in Sipe-2

- Heuristic: prove that there is one possible ordering of the actions that makes the formula true, but don't insert ordering links to enforce that order
- Such a proof is efficient
  - Suppose you have an action A1 with a precondition P
  - Find an action A2 that achieves P (A2 could be initial world state)
  - Make sure there is no action necessarily between A2 and A1 that negates P
- Applying this heuristic for all preconditions in the plan can result in infeasible plans

Comments on HTN planning

- The major idea is to gain efficiency by using the library of preconstructed plans.
- When there is *recursion*, it is undecidable even if the underlying state space is finite.
  - recursion can be ruled out
  - the length of solutions can be bound
  - can use a hybrid POP and HTN approach

Comments on HTN planning (cont'd)

- Subtask sharing is nice, but it takes time/resources to notice the opportunities

  Would interprocedural optimization be a possibility? Consider $tan(x) - sin(x)$. Both have Taylor series approximations:

  $$tan(x) \approx x + \frac{x^3}{3} + \frac{2x^5}{15} + \frac{17x^7}{315}$$
  $$sin(x) \approx x - \frac{x^3}{6} + \frac{x^5}{120} - \frac{x^7}{5040}$$

  It would be nice to share terms but a compiler can only optimize within the code because it does not have the source; and if it did interprocedural optimization tan and sin would always have to be changed together.

Comments on HTN planning (cont'd)

- Suppose that we want to construct a plan with n actions
  - Forward state space planning takes $O(b^n)$ with b allowable actions at each state.
  - HTN planning can construct $d^{(n-1)/(k-1)}$ decomposition trees with d possible decompositions with k actions each
    $\rightarrow$ keeping d small and k large can result in huge savings (long macros usable across a wide range of problems)
  - HTN-based planners do not address uncertainty