Planning Techniques

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Objectives

Specific Objectives

- Main structures used
- Main techniques

Source

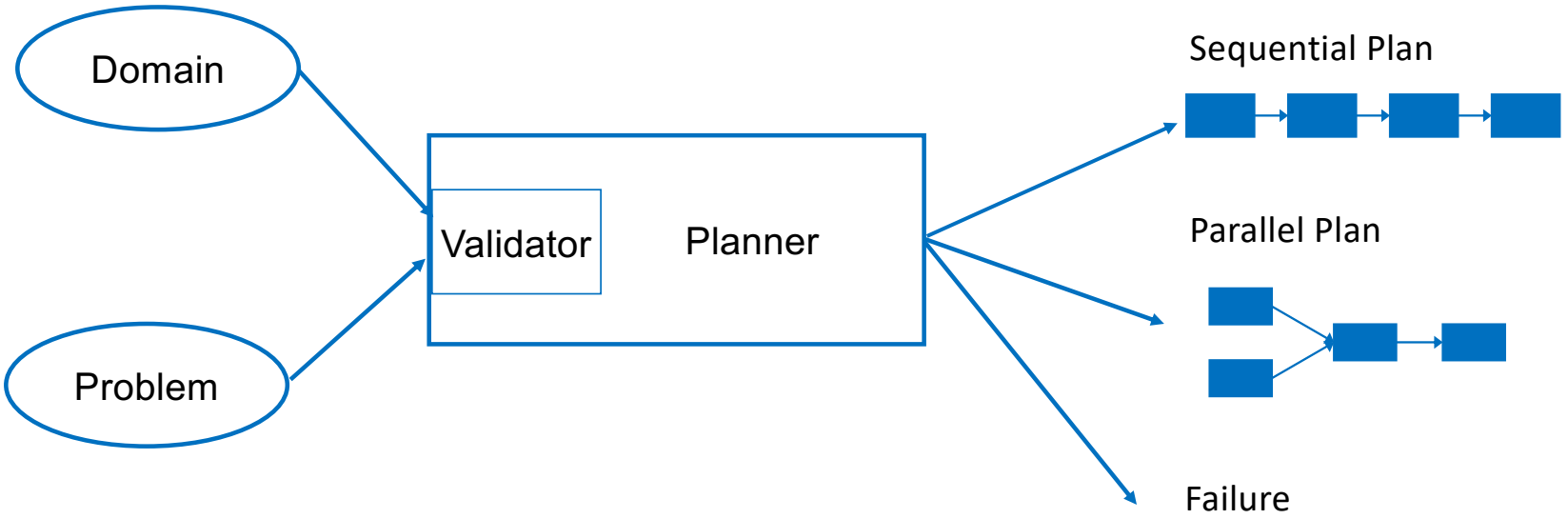
- Stuart Russell & Peter Norvig (2009). Artificial Intelligence: A Modern Approach. (3rd Edition). Ed. Pearsons
- Ghallab, Nau &Traverso (2004). Automated Planning: Theory & Practice. The Morgan Kaufmann Series in Artificial Intelligence
- Dana Nau's slides for Automated Planning. Licensed under License https://creativecommons.org/licenses/by-nc-sa/2.0/

Outline

- **Introduction**
- Classification of algorithms
- Planning techniques
- Conclusions

Introduction

- Nearly all planning procedures are search procedures



Outline

- Introduction
- **Classification of algorithms**
- Planning techniques
- Conclusions

Classification of algorithms

- Criteria for classifying algorithms:
  - How the search is performed (state/plan, progression/regression)
  - Goals ordering: (no)lineal
  - How plans are built: generative (no library plans) or case-based
  - Dealing with uncertainty: contingent and probabilistic
  - Using specific knowledge: domain (in)dependent

Classification of algorithms

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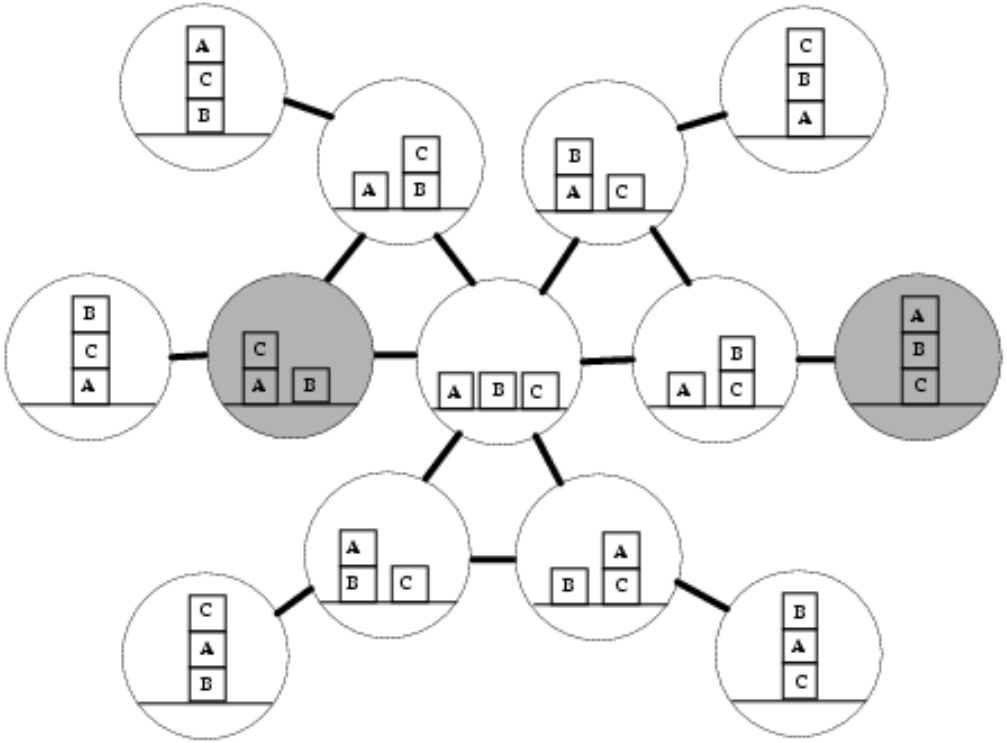
Classification of algorithms: search

- **State-space search in planning**
  - Each node represents a state of the world
  - A plan is a path through the space
- Plan-space search in planning
  - Each node is a set of partially-instantiated operators, plus some constraints
  - Impose more and more constraints, until we get a plan

State Space Search (SSS) (I)

- The easiest way to build a planner is to convert it in a search problem through the state space (SSS)
  - Each node in the tree/graph represents a state of the world
  - Each arc connects worlds that are achieved by executing an action
- Once the planning problem is converted → we can apply any algorithm studied

State Space Search (SSS) (II)



State Space Search (SSS) (III)

- You can incrementally generate the set of reachable states from the initial state by a sequence of actions: *progression*
- The states that are achieved in these sequences can be calculated
  - Checking if the goal has been achieved
  - Checking if the preconditions are satisfied
- Instead of looking forward from the initial state, you can search backward from the goals: *regression*

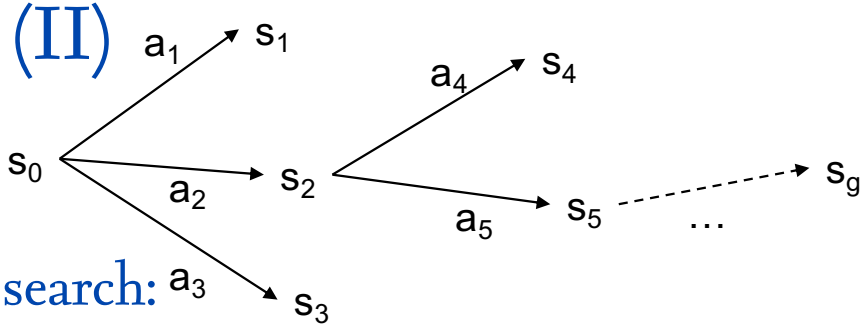
State Space Search (SSS) (IV)

- The algorithm is:
  - Robust? (the plan that returns, works)
  - Complete? (if there is a solution plan, can find it)
- What algorithm is faster?
  - They have the same complexity, both will do approx. ”n" decisions before finding the solution
  - The number of decisions at each branch point suppose to be "b”. Complexity??
  - By experience, the branching factor (b) is smaller in one. What????

State Space Search (SSS): Progression (I)

- Forward-search is *sound*
  - for any plan returned by any of its nondeterministic traces, this plan is guaranteed to be a solution
- Forward-search also is *complete*
  - if a solution exists then at least one of Forward-search's nondeterministic traces will return a solution

State Space Search (SSS): Progression (II)



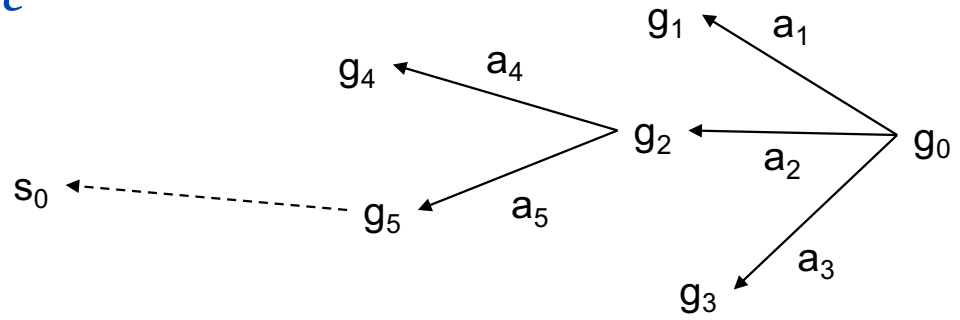
- Some deterministic implementations of forward search:
  - breadth-first, depth-first, best-first (e.g., A*) or greedy search
- Breadth-first and best-first search are sound and complete
  - But they usually aren't practical because they require too much memory
  - Memory requirement is exponential in the length of the solution
- In practice, more likely to use depth-first or greedy search
  - Worst-case memory requirement is linear in the length of the solution
  - In general, sound but not complete

State Space Search (SSS): Progression (III)

- Forward search can have a very large branching factor
  - E.g., many applicable actions that don't progress toward goal
- Why this is bad:
  - Deterministic implementations can waste time trying lots of irrelevant actions
- Need a good heuristic function and/or pruning procedure

State Space Search (SSS): Regression (I)

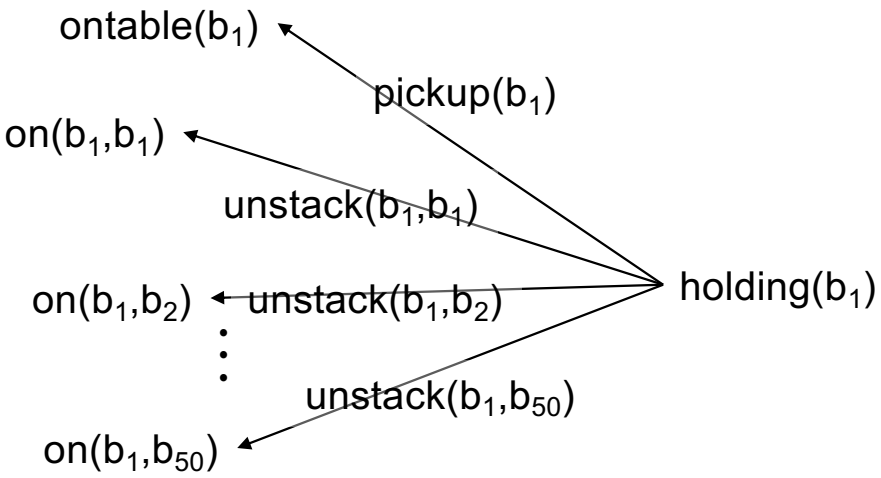
- For forward search, we started at the initial state and computed state transitions
  - new state = $\gamma(s,a)$
- For backward search, we start at the goal and compute inverse state transitions
  - new set of subgoals = $\gamma^{-1}(g,a)$
- To define $\gamma^{-1}(g,a)$, must first define *relevance*
  - An action a is relevant for a goal g if
    - a makes at least one of g's literals true
      - $g \cap \text{effects}(a) \neq \emptyset$
    - a does not make any of g's literals false
      - $g^+ \cap \text{effects}^-(a) = \emptyset$ and $g^- \cap \text{effects}^+(a) = \emptyset$



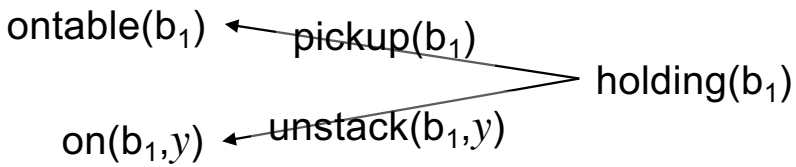
State Space Search (SSS): Regression (II)

- Backward search can *also* have a very large branching factor
  - E.g., an operator o that is relevant for g may have many ground instances a_1, a_2, …, a_n such that each a_i's input state might be unreachable from the initial state
- As before, deterministic implementations can waste lots of time trying all of them
- STRIPS uses this search

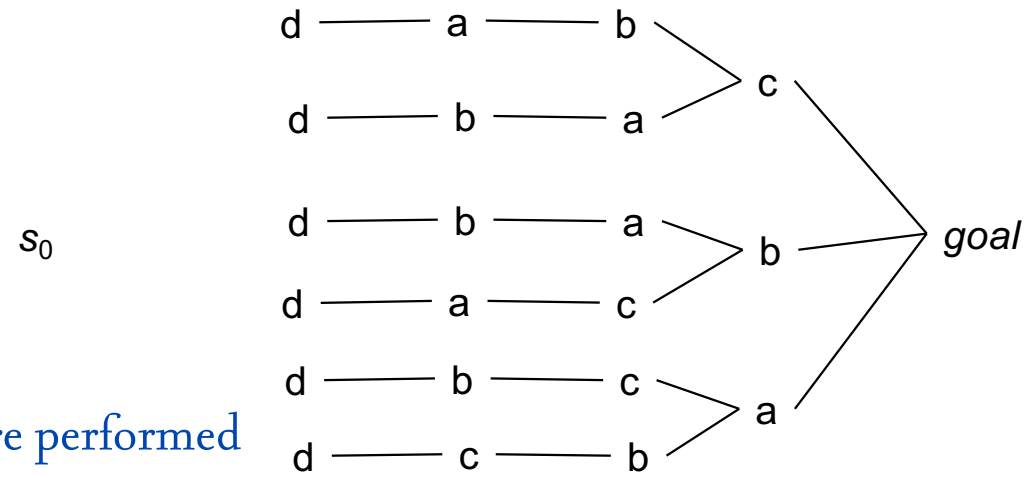
State Space Search (SSS): Lifting



- Can reduce the branching factor of backward search if we *partially* instantiate the operators = is called *lifting*



State Space Search (SSS): Lifting



- More complicated than Backward-search
  - Have to keep track of what substitutions were performed
- But it has a much smaller branching factor, but still can be quite large
- Suppose actions a, b, and c are independent, action d must precede all of them, and there's no path from s_o to d's input state
- We'll try all possible orderings of a, b, and c before realizing there is no solution

Classification of algorithms: search

- State-space search in planning
  - Each node represents a state of the world
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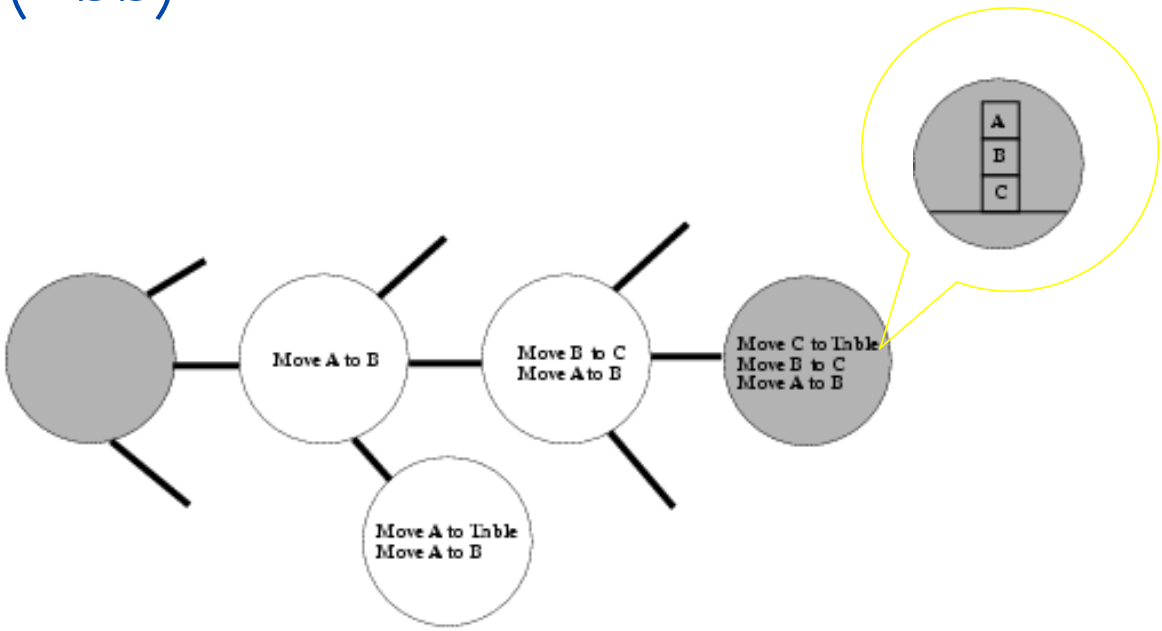
Plan Space Search (PSS)

- In 1974, the planner NOAH (Sacerdoti) was built, the search was conducted through the space of plans (PSS) :
  - Each node in the tree/graph represents a partial plan
  - Each arc represents refining plan operations (add an action to the plan)
  - A set of constraints
- The initial node is a NULL plan and the final node represents the solution plan for the goal
- While SSS has to return the solution path from the initial to the goal states, the goal state in PSS is the solution

Plan Space Search (PSS)



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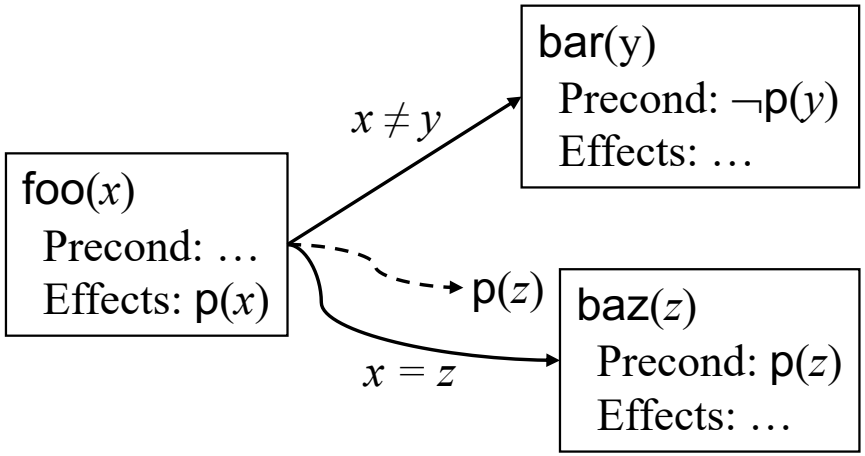
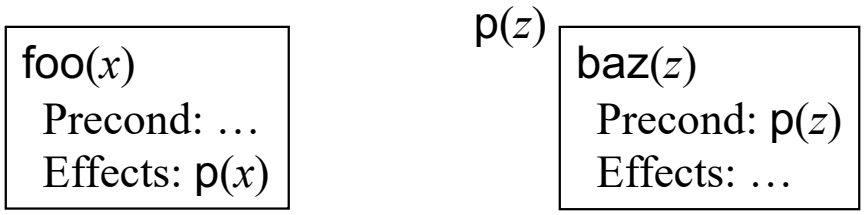
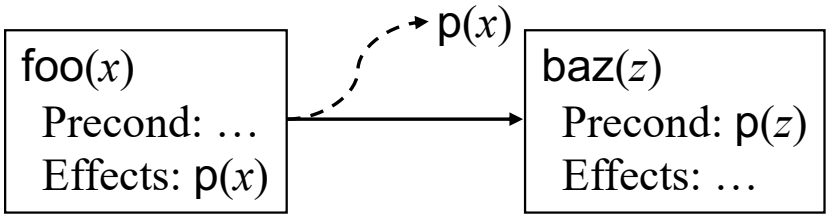


- Backward search from the goal
- Types of constraints:
  - *precedence constraint*: *a* must precede *b*
  - *binding constraints*:
    - inequality constraints, e.g., $v_1 \neq v_2$ or $v \neq c$
    - equality constraints (e.g., $v_1 = v_2$ or $v = c$) and/or substitutions
  - *causal link*: use action *a* to establish the precondition *p* needed by action *b*
- How to tell we have a solution: no more *flaws* in the plan

Plan Space Search (PSS): Flaws

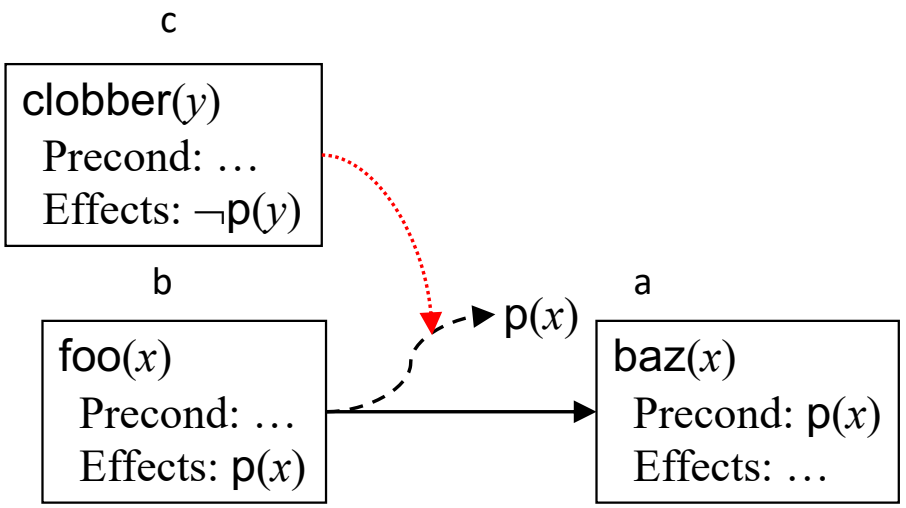
- Open goal:
  - An action a has a precondition p that we haven't decided how to establish
- Resolving the flaw:
  - Find an action b
    - (either already in the plan, or insert it)
  - that can be used to establish p
    - can precede a and produce p
  - Instantiate variables and/or constrain variable bindings
  - Create a causal link





Plan Space Search (PSS): Threat

- Threat: a deleted-condition interaction
  - Action *a* establishes a precondition (e.g., p(*x*)) of action *b*
  - Another action *c* is capable of deleting *p*
- Resolving the flaw:
  - impose a constraint to prevent *c* from deleting *p*
- Three possibilities:
  - Make *b* precede *c*
  - Make *c* precede *a*
  - Constrain variable(s) to prevent *c* from deleting *p*



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- Classification of algorithms
- **Planning techniques**
  - Total Order Planners (TO)
  - Partial Order Planners (POP)
  - Hierarchical Task Network (HTN)
  - Graph-based Planners (GP)
  - SAT-based planners
  - Heuristic Search Planners
- Conclusions

Planning techniques

- TO: the solution is a totally ordered sequence of actions (States / Plans)
- PO: search at the space plans. Implements a "least Commitment approach": only the essential decisions orders are saved
- HTN: network of tasks and constraints
- Graph-based: the search structure is a Planning Graph
- SAT: takes as input a problem, guess the length of the plan and generates propositional clauses
- Heuristic Search Planners: transform planning problems in heuristic problems

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Conclusions

- Planning is an interesting area because it combines logic and search
- We have studied the main planners and the search algorithms that use
- There are actually no better strategies than others
- Competition between approaches and the intersection and combination of techniques has resulted in gains in efficiencies in syst. planning