Multistage Stochastic LP

with Recourse

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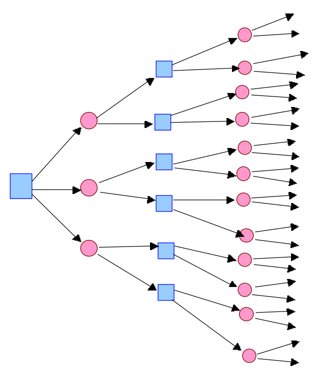
Assume:

- $w = \left(w^1, w^2, \ldots w^H\right)$ is revealed at H different points in time (H is time horizon = # of stages)
- w^t has discrete distribution $F_{w^t|w^{t-1}}$ which is conditional upon the previous outcome w^{t-1}
- x^t (decisions at stage t) depend upon *both* previous decisions $\left(x^1, x^2, \ldots x^{t-1}\right)$ *and* previous outcomes $\left(w^1, w^2, \ldots w^t\right)$
- Recourse is *complete*, i.e., all optimization problems are feasible with respect to both random outcomes and previous decisions.

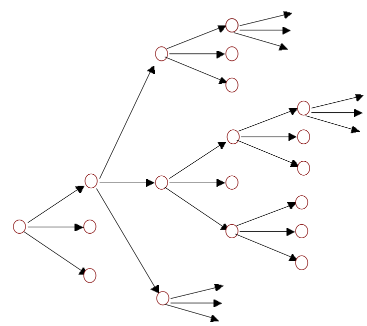
Decision Tree Representation (squares ~ decisions, circles ~ random outcomes)



Scenario Tree:

Each node in the tree corresponds to a **scenario**.

Each stage t scenario *j* has a single **ancestor** scenario *a(j)* at stage t-1, and perhaps several **descendent** scenarios at stage t+1.



The Multistage Stochastic Linear Program (with H stages) can be stated:

$$\min_{x_1} \; c_1 x_1 + E\left\{\min_{x_2} c_2\left(w^1\right) x_2\left(w^1\right) + \cdots + E\left[\min_{x_H} c_H\left(w^{H-1}\right) x_H\left(w^{H-1}\right)\right] \cdots\right\}$$

s.t.

$$\begin{aligned} W_1 x_1 &= h_1 \\ T_1\left(w^1\right) x_1 + W_2 x_2\left(w^1\right) &= h_2\left(w^1\right) \\ &\vdots \\ T_{H-1}\left(w^{H-1}\right) x_{H-1} + W_H x_H\left(w^{H-1}\right) &= h_H\left(w^{H-1}\right) \\ x_1 \geq 0, x_2\left(w^1\right) \geq 0, \cdots x_H\left(w^{H-1}\right) &\geq 0 \end{aligned}$$

Recursive statement of problem:

$$\min_{x_1} \; c_1 x_1 + Q_2\left(x_1\right)$$

subject to

$$W_1 x_1 = h_1, \quad x_1 \geq 0$$

where, for t=2, 3, ….H:

$$Q_t\left(x_t\right) = \sum_j p_t^j Q_t^j\left(x_t^j\right)$$

$$Q_t^j\left(x_{t-1}^{a(j)}\right) = \min_{x_t}\left\{c_t^j x_t + Q_{t+1}\left(x_t\right): \; W_t x_t = h_t^j - T_{t-1}^{a(j)} x_{t-1}^{a(j)}, x_t \geq 0\right\}$$

The function $Q_t^j\left(x\right)$ is convex and (in the case of *discrete* random outcomes) piecewise-linear.

Nested Benders' Decomposition

The piecewise-linear function $Q_t^j\left(x_t\right)$ in the problem at scenario j of stage t is approximated by a master problem

$$\underline{Q}_t^j\left(x_t\right) = \min \; c_t^j x_t + q$$

subject to

$$\begin{aligned} W_t x_t &= h_t^j - T_{t-1}^{a(j)} x_{t-1}^{a(j)} \\ q &\geq a_t^{j,k} x_t + b_t^{j,k}, \quad k = 1,2,\ldots K_t^j \\ x_t &\geq 0 \end{aligned}$$

where

$x_{t-1}^{a(j)}$ is the "trial" decision from the ancestor scenario *a(j)*, and

$a_t^{j,k} x_t + b_t^{j,k}$ are the K_t^j supports of $E\left[Q_{t+1}^j\left(x_t\right)\right]$ generated by the descendents of scenario j.

After solving each approximating problem above,

- the dual variables are passed up to the ancestor scenario, and
- the primal variables x_t^j are passed to the descendent scenarios.