Lecture #18

ERDM

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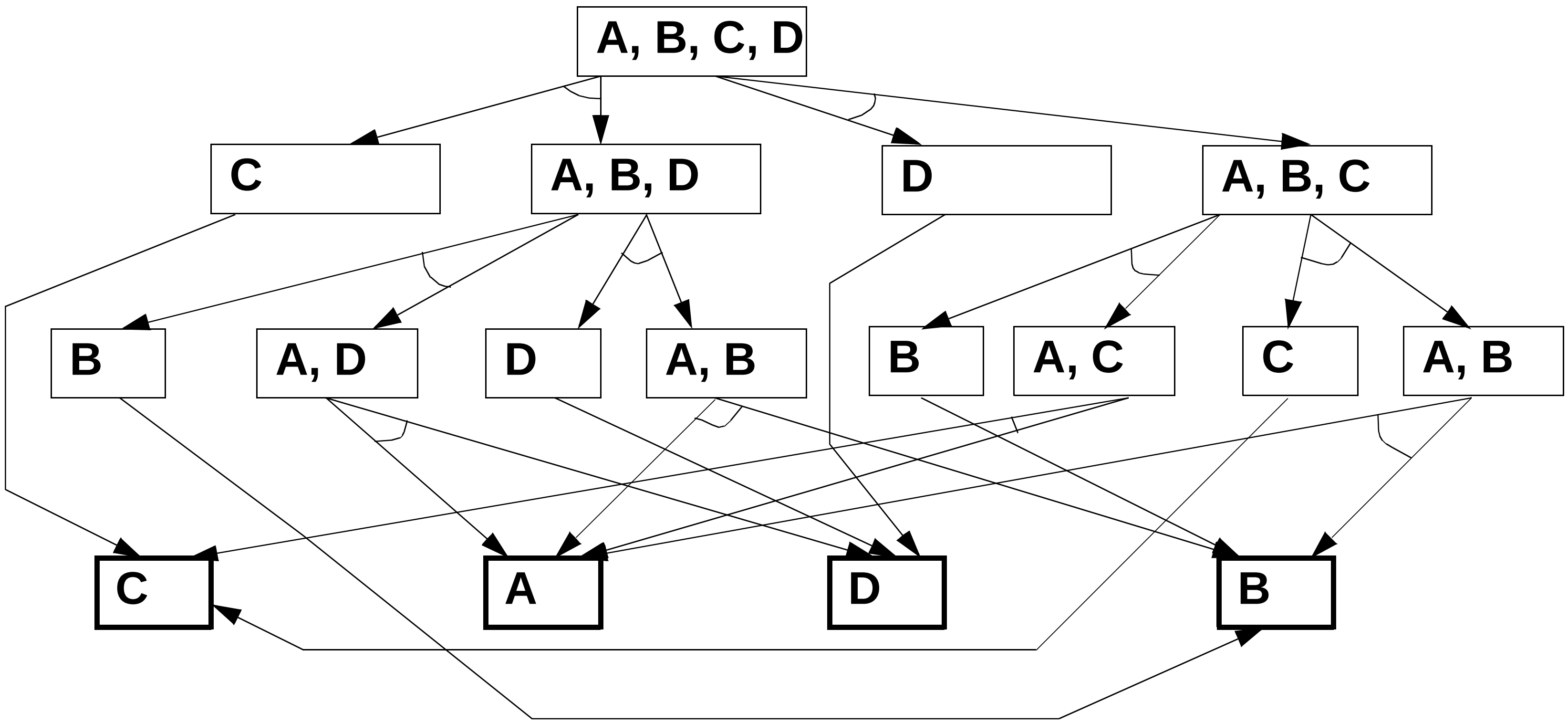
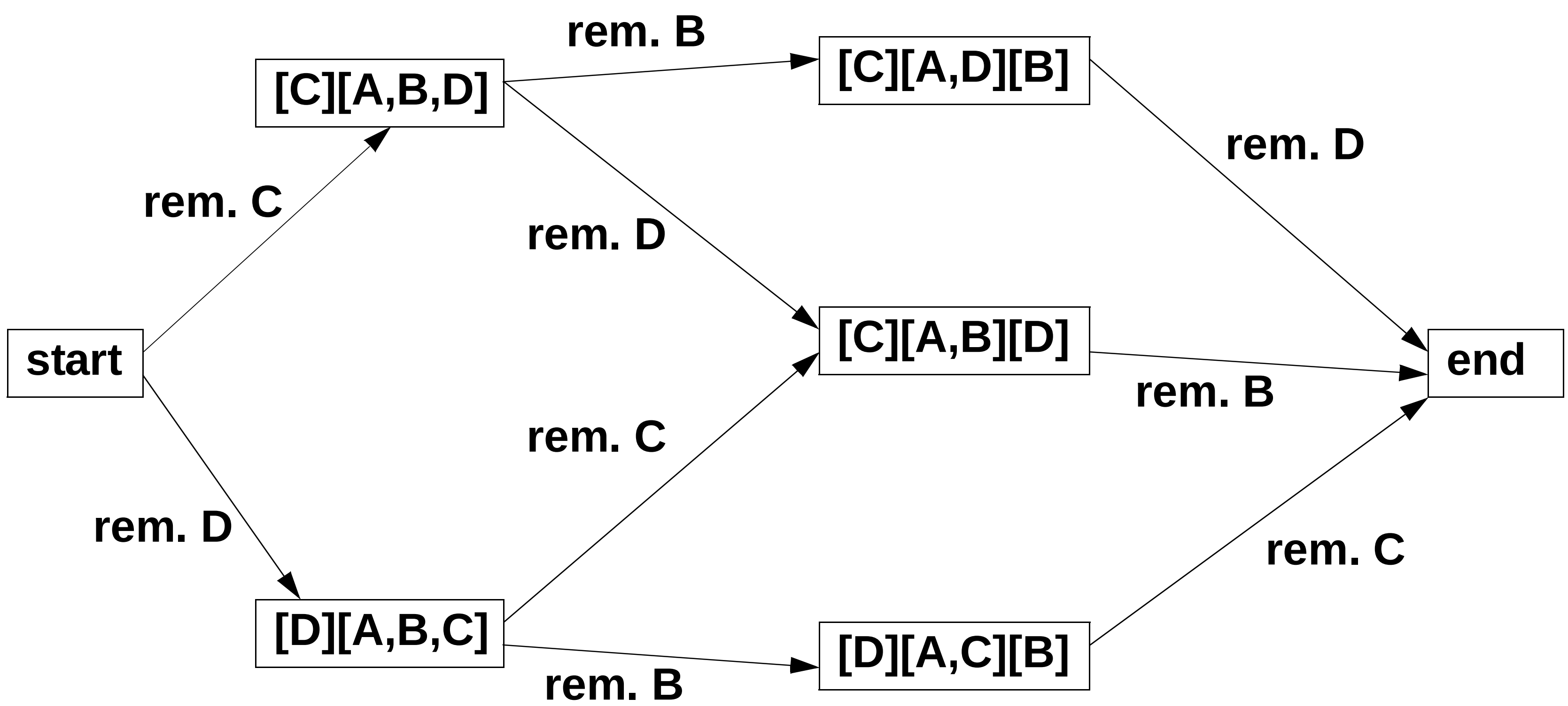
Disassembly Sequence
("and or" diagram)



Disassembly Sequence (network model)



Separate subassemblies in [ ]

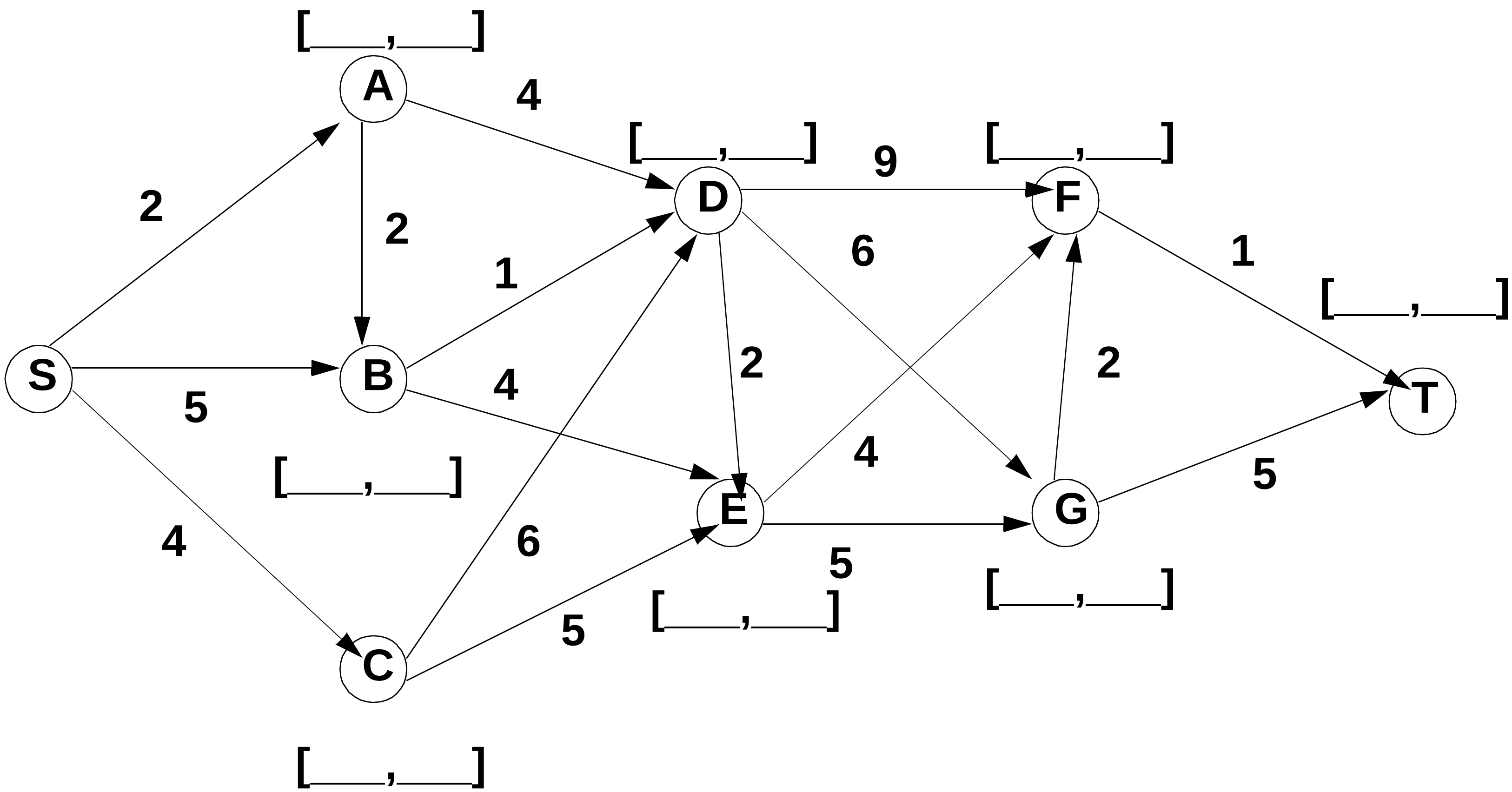
Disassembly Analysis

- **The network model describes the disassembly process flow**
- **Disassembly steps (e.g., remove part A) are characterized by arcs in the figure.**
- **Disassembly configurations (e.g., C is separate from parts A+B+D) appear as nodes in the figure.**
- **Industrial Engineering (Operations Research) techniques can be used to analyze the system.**

Selecting a Disassembly Sequence

- Let's say we take the product apart a few times and we try to explore each of the pathways in the network model (sometimes referred to as a directed graph)
- We can establish a time for each disassembly operation (or perhaps even time distributions).
- Alternatively, there are handbooks that list the times required to perform certain operations.
- We could select the pathway that produces the minimum time.

Minimum Completion Time



Minimum Time Problem

- The minimum time problem we have just solved is also referred to as the "shortest path problem". Floyd's algorithm -- Dijkstra's algorithm
- For each node, we consider all ways to arrive at that node, and we select the way that is the minimum.
- By-product: Best way to get to every configuration.
- In principle, we could use this approach to figure out the best way to completely disassemble the entire product.

Partial Disassembly

- **Is complete disassembly the best way to go?**
- **Maybe, if the product is designed correctly, we can quickly extract the parts that are**
  - **Undamaged**
  - **Of high value**
  - **Hazardous**
- **Then, recycle the material that remains in the product.**
- **What impact does partial disassembly have on our network model??**

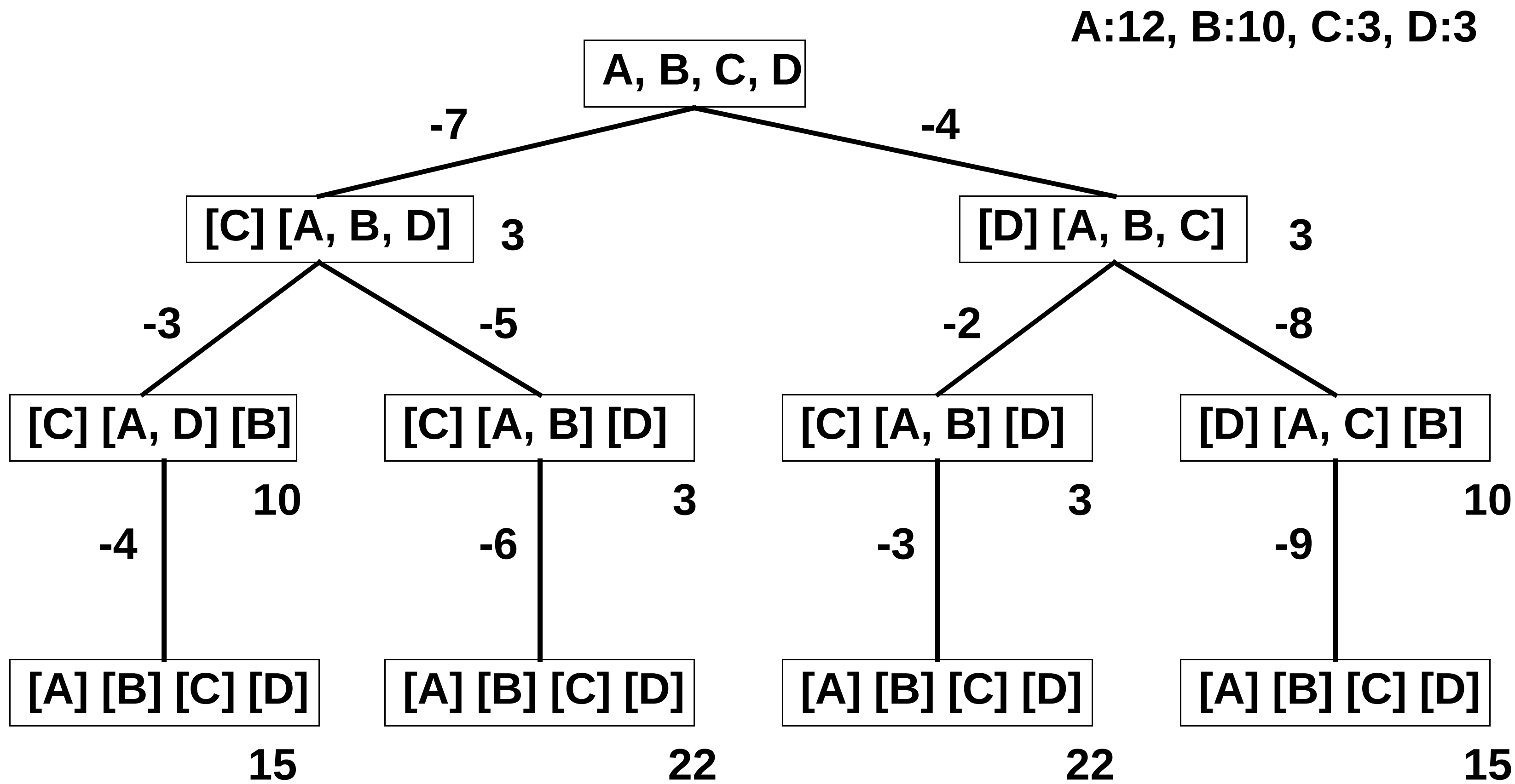
Modeling Partial Disassembly

- **Associated with each disassembly activity is a cost. This cost includes the time to complete the task as well as other activity-related costs. (Costs are negative)**

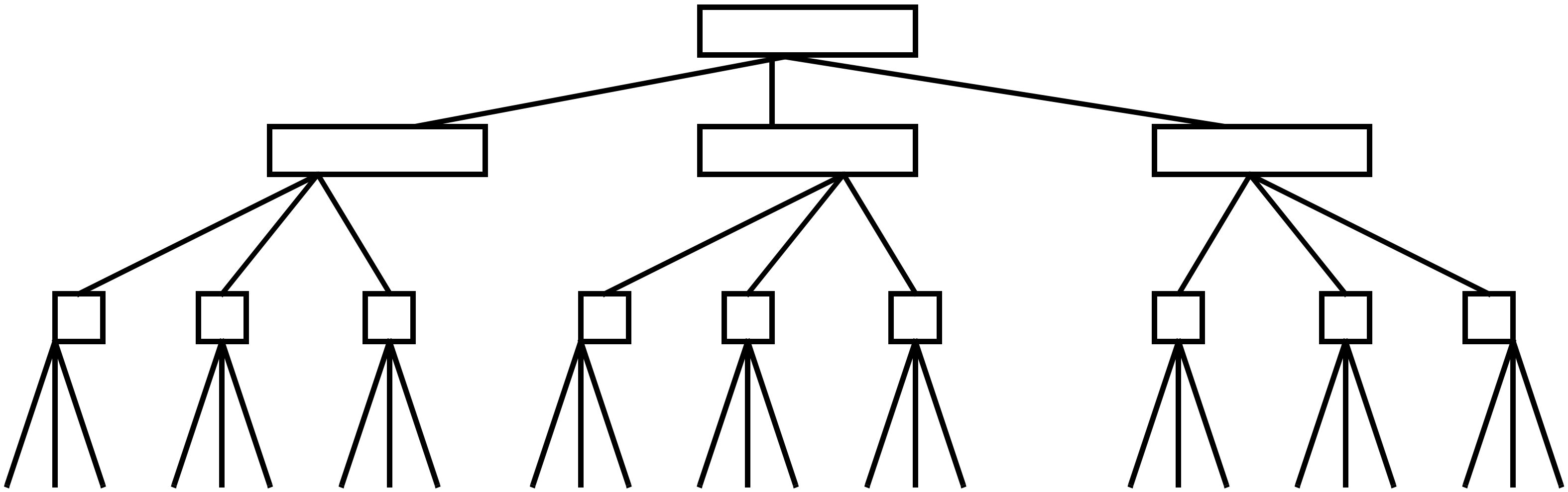
- **At some nodes in our network model, we free up an individual part. When this happens, it is expected that revenue will be generated. (Revenue is positive)**

- **The challenge is then to figure out in which order to remove parts, and when (and if) to stop.**

Maximum Profit Partial Disassembly



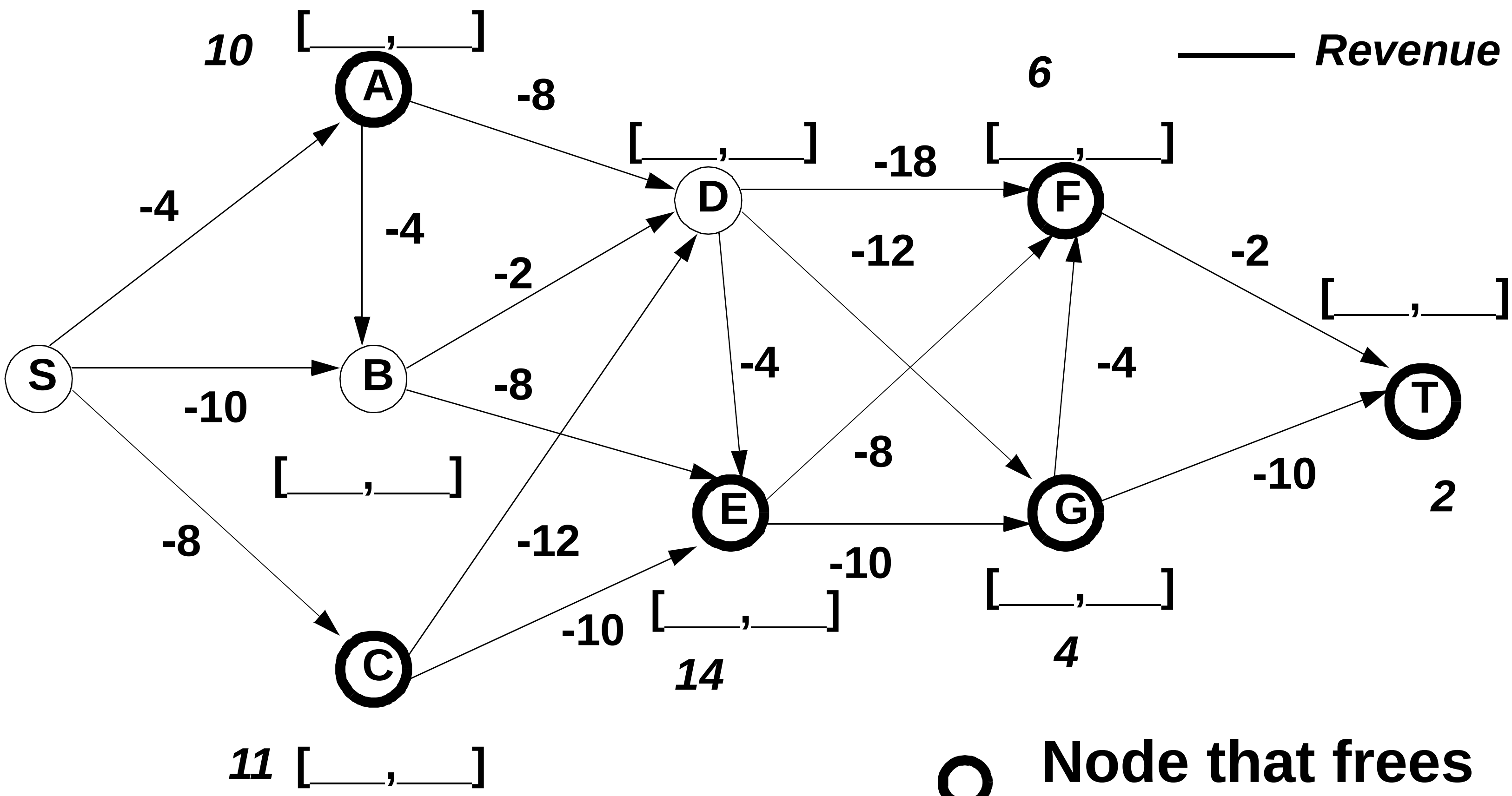
Disassembly Paths



Number of possible disassembly paths grows quickly!!

Let's use our network model instead.

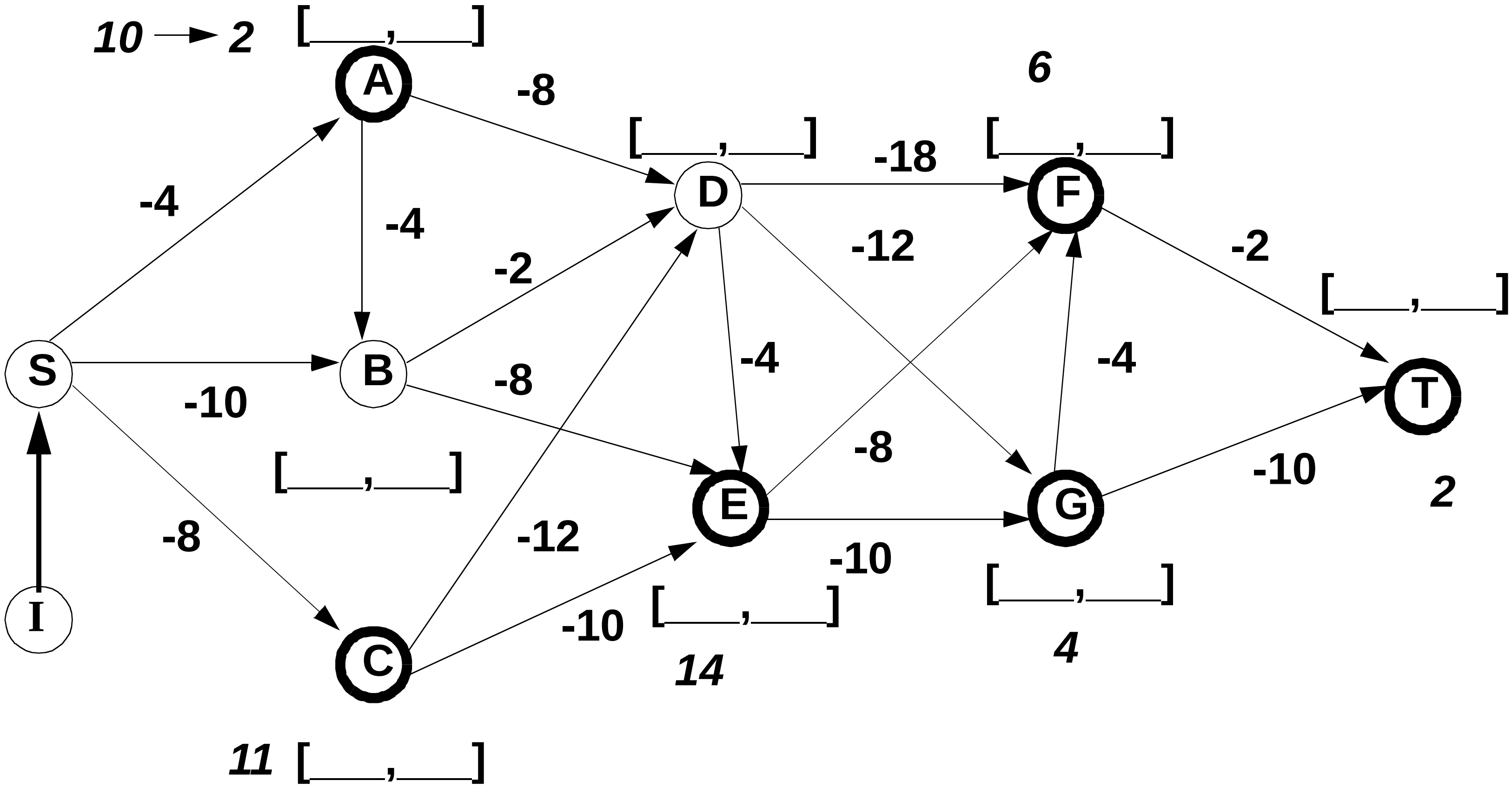
Maximum Profit



Node that frees up a component

Partial Disassembly

What if the product has been used and has undergone damage/wear?
We may need to select disassembly path based on an initial inspection.



Recap

We've examined the influence of product design characteristics on environmental performance:

- **Concept design**
- **Material selection**
- **Geometric features**
- **Part dimensions**
- **Assembly/Disassembly**

Now, given this background, what must a designer do to reduce environmental impact?

Concept Design

We talked about using QFD to incorporate the "voice of the environment" in the design process.

- **Most importantly -- while maximum degrees of freedom remain, CONSIDER ENVIRONMENTAL CONSEQUENCES!!**
- **Think "out of the box" -- how can customer needs be met from a minimum energy, minimum resource, minimum waste standpoint?**
- **Ideas: analogies in nature, brainstorming, etc.**

Concept Design (cont.)

- What is the plan for the product at the end of its life??
  - Recycling?
  - Remanufacturing?
  - Reuse?
  - No plan? or Disposal?

- Product stewardship
  - Selling use versus selling a product
  - Lease programs
  - Increased software content (less hardware)
  - Reverse logistics (recovery infrastructure) in place?

Material Selection

Desirable characteristics of materials:

- **Abundant, nontoxic, nonregulated materials**
- **Avoid complex materials, coatings, surface treatments**
- **Natural materials over synthetic materials**
- **Minimize the use of different materials**
- **Try to use recycled materials when possible**

Material Abundance

Infinite supply	**Ar, Br, Ca, Cl, Kr, Mg, N, Na, O, Rn, Si, Xe**
Ample supply	**Al(Ga), C, Fe, H, K, S, Ti**
Adequate supply	**I, Li, P, Rb, Sr**
Potentially limited supply	**Co, Cr, Mo(Rh), Ni, Pb (As,Bi), Pt (Ir, Os, Pd, Rh, Ru), Zr (Hf)**
Potentially highly limited supply	**Ag, Au, Cu (Se, Te), He, Hg, Sn, Zn (Cd, Ge, In, Tl)**

Materials -- Energy Requirements

Energy Input (GJ/Mg)

Metal	Primary Production	Secondary Production
Steel	31	9
Copper	91	13
Aluminum	270	17
Zinc	61	24
Lead	39	0
Titanium	430	140

- **Energy advantage of recycled materials**

Materials -- Solid Waste

Metal	Ore (Tg)	Avg. Grade (%)	Residues (Tg)
Copper	910	0.91	900
Iron	820	40.0	490
Lead	120	2.5	117
Aluminum	100	23.0	77
Nickel	35	2.5	34
Others	925	8.1	850
Total	2910		2460

- **Destruction of local habitats**

Geometric Features

Remember discussion of reprocessability index

- **Complexity makes reuse / remanufacturing more difficult. But assembly and disassembly may be simplified.**
- **Large part size promotes recycling, but uses more resources.**
- **Reduce stresses (avoid thin sections & stress risers) -- enhance product life -- maintain product value.**
- **Mating/contact surfaces -- discourage reuse and re-manufacturing -- replaceable inserts an option.**
- **Removable features favored.**

Part Dimensions

Remember discussion of Product Value Model

- **Adopt the long term view -- want to think about the WHOLE USAGE STAGE.**
- **Maximize product life and consumer satisfaction over the life of the product. Want maximum value.**
- **Remember product performance degrades over time.**
- **Product-to-product variability increases over time.**

Product Configuration

- **How are the components within a product related to one another? Assembly/Disassembly**

- **We want to promote disassembly.**
  - **Tall hierarchy -- Modular Product Design**
  - **Flat hierarchy -- may favor replacement of individual components**
  - **Controlled or Destructive Disassembly**
  - **Single direction for insertion/removal**

Remember discussion of liaison diagrams and network model for selecting disassembly order