Basics of engineering economics

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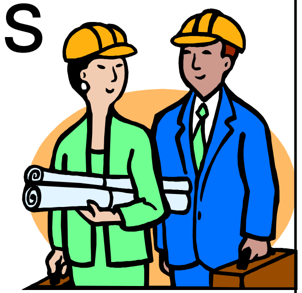
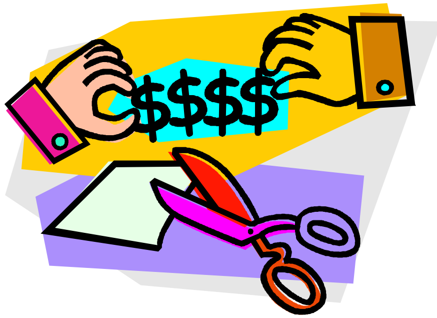
What is Engineering Economics?

- "Engineering is the profession in which a knowledge of the mathematical and natural sciences gained by study, experience, and practice is applied with judgment to develop ways to utilize, economically, the materials and forces of nature for the benefits of mankind" -- Accreditation Board for Engineering and Technology (ABET), USA



What is Engineering Economics?

- Just being able to build/create things is not enough. Must be able to do it economically
  - Engineering processes involve decisions and tradeoffs; each has a different cost, i.e., something you give up (usually money)



- Examples
  - Construct a building: Where and how to build it?
  - Design a product: What features? When to launch?

What is Engineering Economics?

- Engineering Economics
  - It involves the systematic evaluation of the economic merits of proposed solutions to engineering problems
  - It is the dollars-and-cents side of the decisions that engineers make or recommend as they work to position a firm to be profitable in a highly competitive marketplace
  - Its mission is to *balance* these trade-offs in the most economical manner

Engineering economic analysis & engineering design process

1. Problem definition
2. Problem formulation and evaluation
3. Synthesis of possible solutions (alternatives)
4. Analysis, optimization, and evaluation
5. Specification of preferred alternative
6. Communication via performance monitoring

What is Engineering Economics?

- Analysis process
  - 1. <u>Problem recognition, definition, and evaluation</u>
    - What is the need? The more concrete the description, the better for further analysis
    - Evaluation of the problem typically includes refinement of needs and requirements, and information from the evaluation phase may change the original problem formulation
  - 2. <u>Develop the alternatives</u>
    - What are the possible courses of actions?
    - Screening alternatives to select a smaller group for further analysis

What is Engineering Economics?

- Analysis process (cont'd)
  - 3. <u>Focus on the differences</u>
    - Only the differences in the alternatives are relevant to their comparison. If all options are equal, then taking any one of them will do
  - 4. <u>Use a consistent viewpoint</u>
    - Define and evaluate the alternatives and their outcomes from a fixed perspective
  - 5. <u>Use a common unit of measure</u>
    - Make sure we are comparing options on an equal basis, i.e., not comparing oranges with apples

What is Engineering Economics?

- Analysis process (cont'd)
  - 6. Consider all relevant criteria and develop prospective outcomes
    - What is the objective? Single or multiple objectives?
    - Typically measured by cash flow — Do I make money?
    - Non-monetary factors can also be important (e.g., reputation, customer/employee satisfaction, long-term sustainability, etc.) However, these could be tricky to measure
  - 7. Making risk and uncertainty explicit
    - Can be philosophical, e.g., what is risk? Also, what kind of information about the uncertainty do we know? Scenarios? Probabilities?

What is Engineering Economics?

- Analysis process (cont'd)
  - 8. <u>Revisit your decisions</u>
    - Things may not turn out as expected
    - Typically, decisions and outcomes are not in "one-shot", i.e., they evolve dynamically over time
    - Factors affecting the outcome may change, and hence the decisions must adapt
    - Monitoring project performance during its operational phase improves the achievement of related goals and reduces the variability in desired results

Example: Buy, Rent or Repair?

- You wreck your car! And you absolutely need one to get around
  - A wholesaler offers $2,000 for the wrecked car, and $4,500 if it is repaired. The car's standing mileage is 58,000 miles
  - Your insurance company offers $1,000 to cover the cost of the accident
  - To repair the car costs $2,000
  - A newer second–hand car costs $10,000 with a standing mileage of 28,000 miles
  - A part–time technician can repair the car for $1,100, but it takes a month. In the meantime, you need to rent a car, which costs $400 per month.
- Question: What should you do?

Example: Buy, Rent or Repair?

No panic! Apply the engineering economic analysis procedure.

Step 1: Define the problem
In this case, it is simple — you need a car!

Step 2: Develop alternatives
You have several options.
(A) Sell the wrecked car and buy the second-hand car. (Of course you would not just dispose the wrecked car.)

(B) Repair the car and keep it.

(C) Repair the car, sell it, and then buy the second-hand car.

(D) Let the part-time technician repair the car and rent in the meantime. Afterwards, keep the car.

(E) Let the part-time technician repair the car and rent in the meantime. Afterwards, sell the car and buy the second-hand car.

Example: Buy, Rent or Repair?

Step 3: Develop prospective outcomes via cash flows

(A) Sell the wrecked car and buy the second-hand car. \$2,000 + \$1,000 – \$10,000 = –\$7,000

(B) Repair the car and keep it. \$1,000 – \$2,000 = –\$1,000

(C) Repair the car, sell it, and then buy the second-hand car. \$1,000 – \$2,000 + \$4,500 – \$10,000 = –\$6,500

(D) Let the part-time technician repair the car and rent in the meantime. Afterwards, keep the car. \$1,000 – \$1,100 – \$400 = –\$500

(E) Let the part-time technician repair the car and rent in the meantime. Afterwards, sell the car and buy the second-hand car. \$1,000 – \$1,100 – \$400 + \$4,500 – \$10,000 = –\$6,000

Example: Buy, Rent or Repair?

Step 4: Use a consistent criterion
Let us just focus on your asset value immediately after the decision is made. (We are ignoring other things, such as higher future insurance costs, resell value of the second-hand car, etc.)

Step 5: Compare the alternatives

(A) Sell the wrecked car & buy the 2nd-hand car. $10,000 – $7,000 = $3,000

(B) Repair the car and keep it. $4,500 – $1,000 = $3,500

(C) Repair the car, sell it, and then buy the second-hand car. $10,000 – $6,500 = $3,500

(D) Let the part-time technician repair the car and rent in the meantime. Afterwards, keep the car. $4,500 – $500 = $4,000

(E) Let the part-time technician repair the car and rent in the meantime. Afterwards, sell the car and buy the second–hand car. $10,000 – $6,000 = $4,000

Example: Buy, Rent or Repair?

Step 6: Choose a preferred alternative after considering risk and uncertainties

From the asset value point-of-view, (D) and (E) are equally good. To differentiate them, we need other criteria. Say, if the repaired car has a higher risk of failing, then we would prefer (E).

Step 7: Revisit the decision

Road test the newer car and confirm your decision.

Engineering Economic Decisions

Discussion Topics:

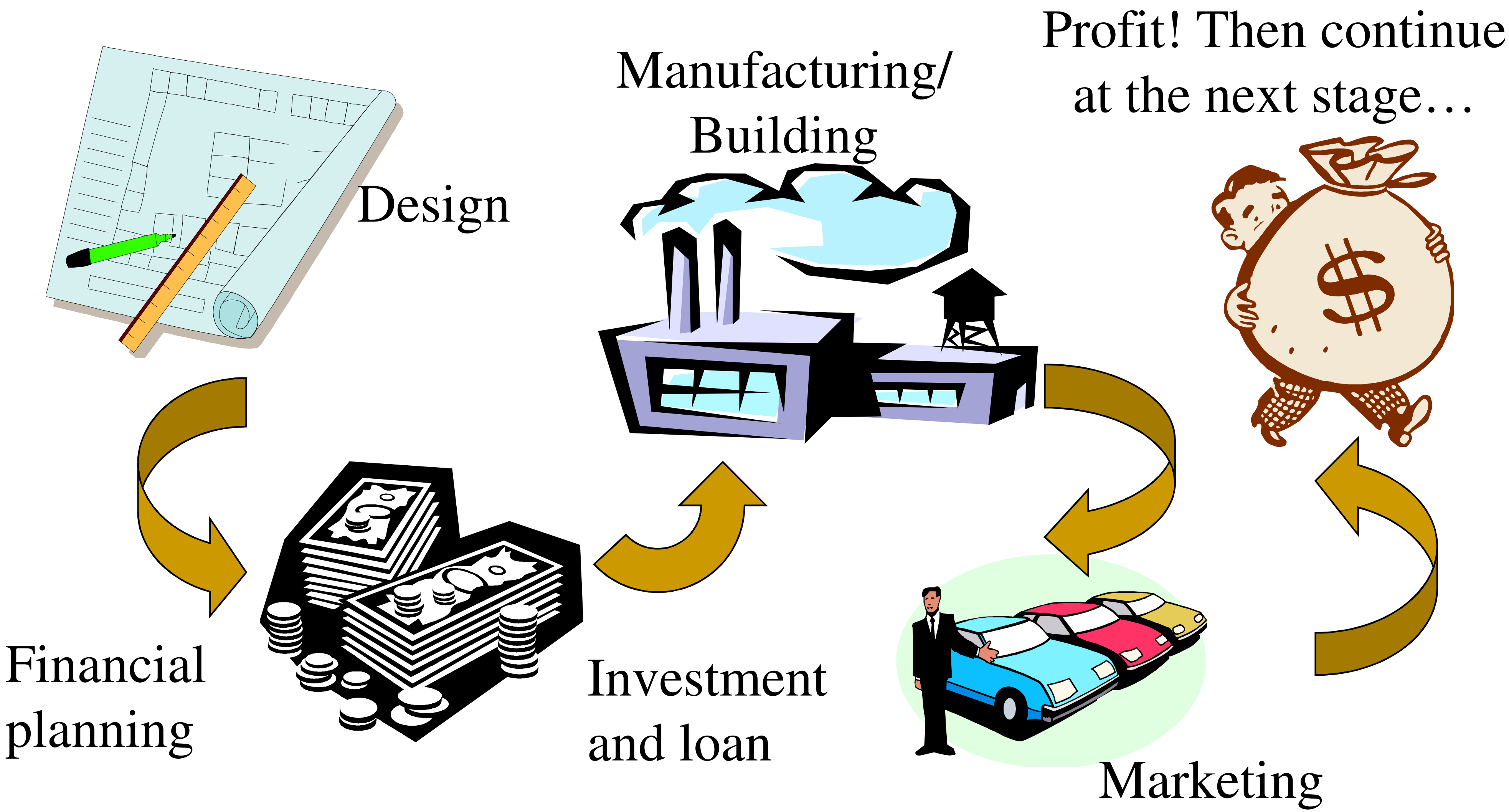
- Rational Decision-Making Process
- Economic Decisions
- Predicting the Future
- Role of Engineers in Business

Engineering Economic Decisions

- Rational Decision-Making Process
  - 1. Recognize a decision problem
  - 2. Define the goals or objectives
  - 3. Collect all the relevant information
  - 4. Identify a set of feasible decision alternatives
  - 5. Select the decision criterion to use
  - 6. Select the best alternative

Engineering Economic Decisions

Needed in the following (connected) areas:



Engineering Economic Decisions

What Makes Engineering Economic Decisions Difficult?

- Predicting the Future
  - Estimate a required investment
  - Forecast a product demand
  - Estimate a selling price
  - Estimate a manufacturing cost
  - Estimate a product life

Role of Engineers in Business

Create & Design

- Engineering Projects

↓

Analyze

- Production Methods
- Engineering Safety
- Environmental Impacts
- Market Assessment

→

Evaluate

- Expected Profitability
- Timing of Cash Flows
- Degree of Financial Risk

→

Evaluate

- Impact on Financial Statements
- Firm's Market Value
- Stock Price

Accounting Vs. Engineering Economy

Evaluating past performance

Evaluating and predicting future events

Accounting

Engineering Economy

Past

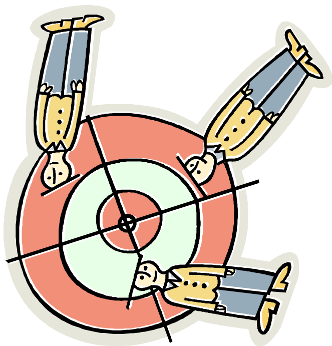
Future

Present

Engineering Economic Decisions

Key factors in selecting good engineering economic decisions:

Objectives, available resources, time and uncertainty are the key defining aspects of all engineering economic decisions




Engineering Projects & Decisions

Large-scale projects:

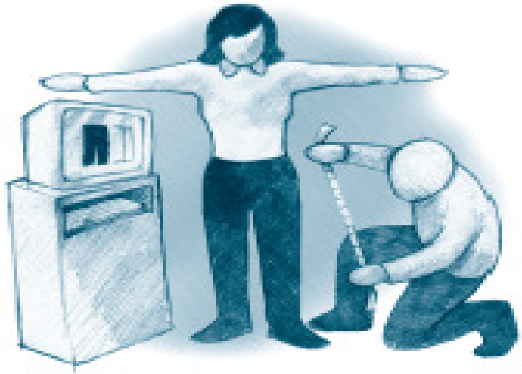
- Requires a large sum of investment
- Can be very risky
- Takes a long time to see the financial outcomes
- Difficult to predict the revenue and cost streams

Engineering Projects & Decisions

- Examples of strategic engineering economic decisions (in the manufacturing sector):
  - Service Improvement
  - Logistics and Distribution
  - Equipment and Process Selection
  - Equipment Replacement
  - New Product and Product Expansion
  - Cost Reduction or Profit Maximization

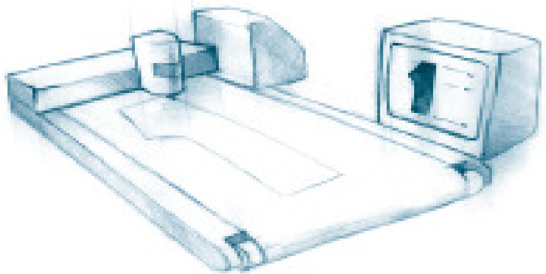
Service Improvement

- How many more jeans would Levi need to sell to justify the cost of additional robotic tailors?

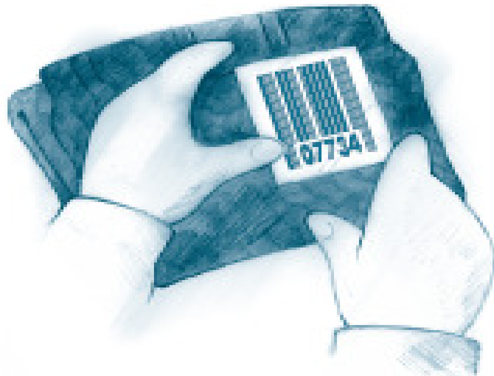


A sales clerk measures the customer using instructions from a computer as an aid.

The clerk enters the measurements and adjusts the data based on the customer's reaction to the samples.



The final measurements are relayed to a computerized fabric cutting machine at the factory.

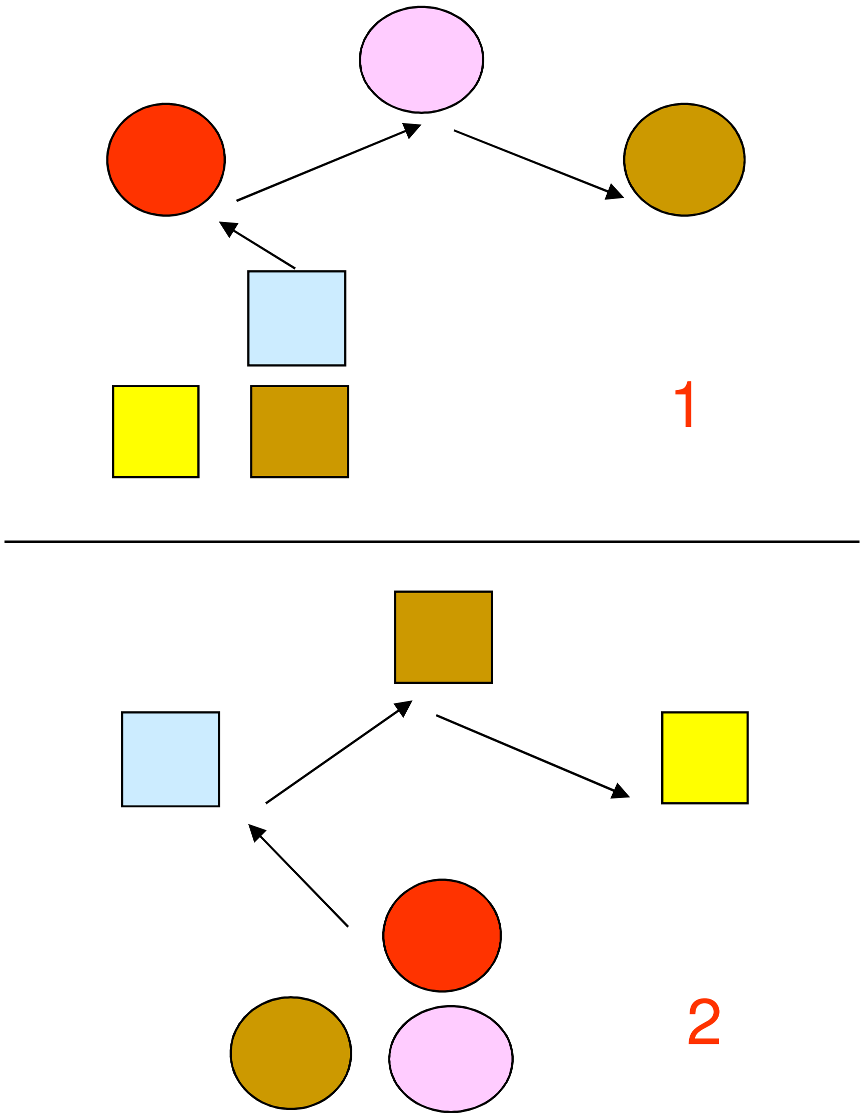


Bar codes are attached to the clothing to track it as it is assembled, washed, and prepared for shipment.

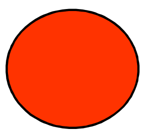
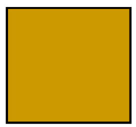
FIGURE 1.6 "From Data to Denim": Making customized blue jeans for women, a new computerized system being installed at some Original Levi's Stores allows women to order customized blue jeans

Logistics and Distribution:
Example - Healthcare Delivery

- 1. Traditional Plan: Patients visit each service providers
- 2. New Plan: Each service provider visits patients

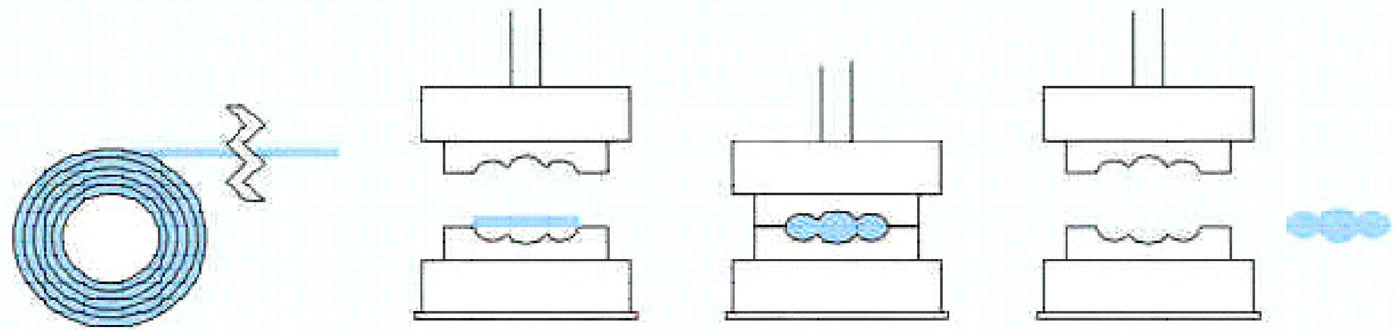


Which one of the two plans is more economical? The answer typically depends on the type of patients and the services offered. Examples?

 ***: service providers***  ***: patients***

Equipment & Process Selection

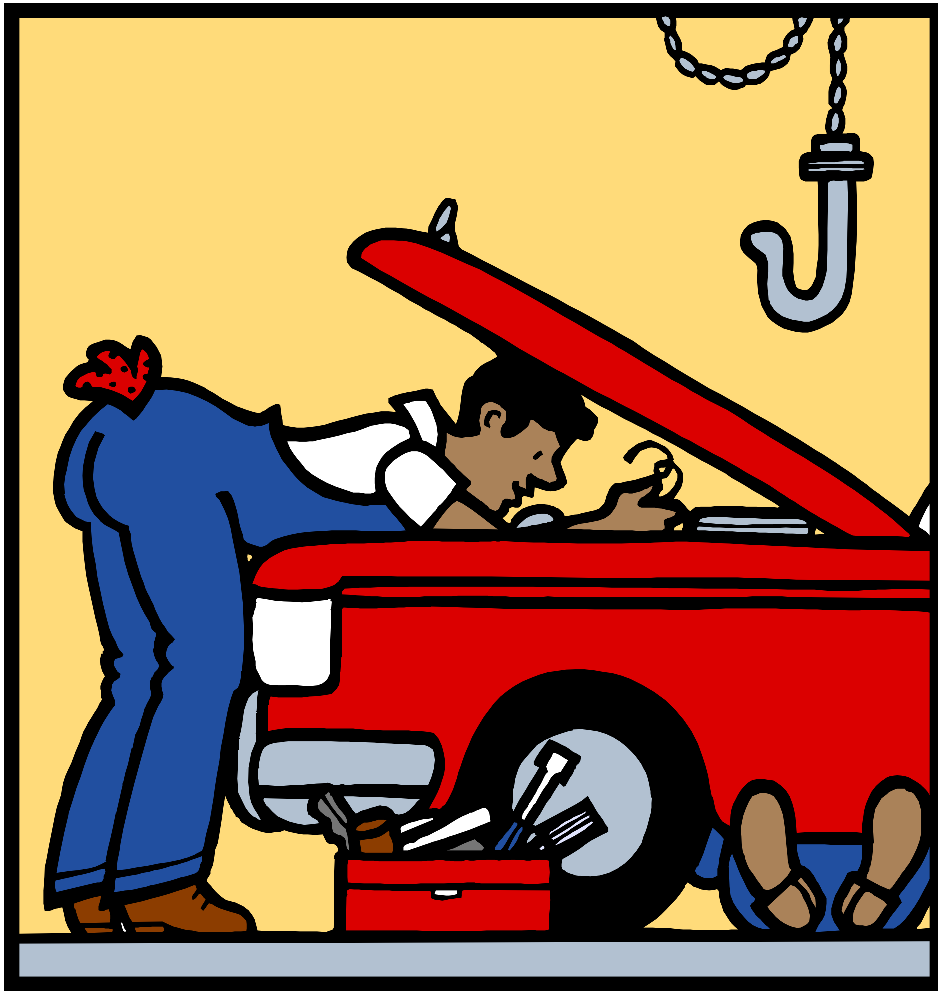
- How do you choose between using alternative materials for an auto body panel?
- The choice of material will dictate the manufacturing process and the associated manufacturing costs



Description	Plastic SMC	Steel Sheet Stock
Material cost ($/kg)	$1.65	$0.77
Machinery investment	$2.1 million	$24.2 million
Tooling investment	$0.683 million	$4 million
Cycle time (minute/part)	2.0	0.1

Equipment Replacement Problem

- Now is the time to replace the old machine?
- If not, when is the right time to replace the old equipment?



New Product and Product Expansion

- Shall we build or acquire a new facility to meet the increased (increasing forecasted) demand?
- Is it worth spending money to market a new product?

In the most general sense, Engineers have to make decisions under resource constraints, and in presence of uncertainty.

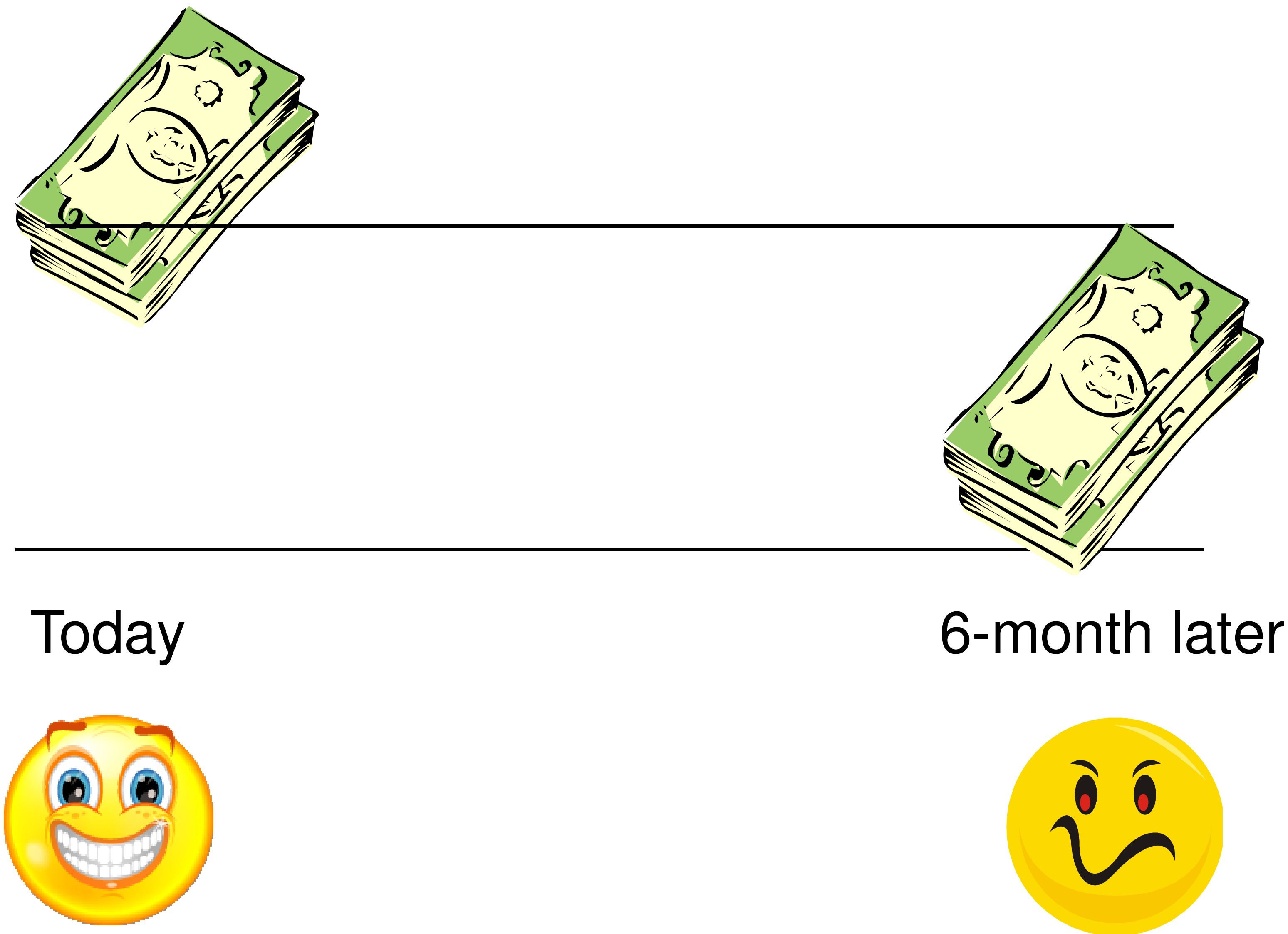
Cost Reduction

- Should a company buy equipment to perform an operation now done manually?
- Should spend money now in order to save more money later?
- The answer obviously depends on a number of factors

Fundamental Principles of Economics

- **Principle 1:** An instant dollar is worth more than a distant dollar
- **Principle 2:** Only the relative (pair-wise) difference among the considered alternatives counts
- **Principle 3:** Marginal revenue must exceed marginal cost, in order to carry out a profitable increase of operations
- **Principle 4:** Additional risk is not taken without an expected additional return of suitable magnitude

Principle 1: An instant dollar is worth more than a distant dollar

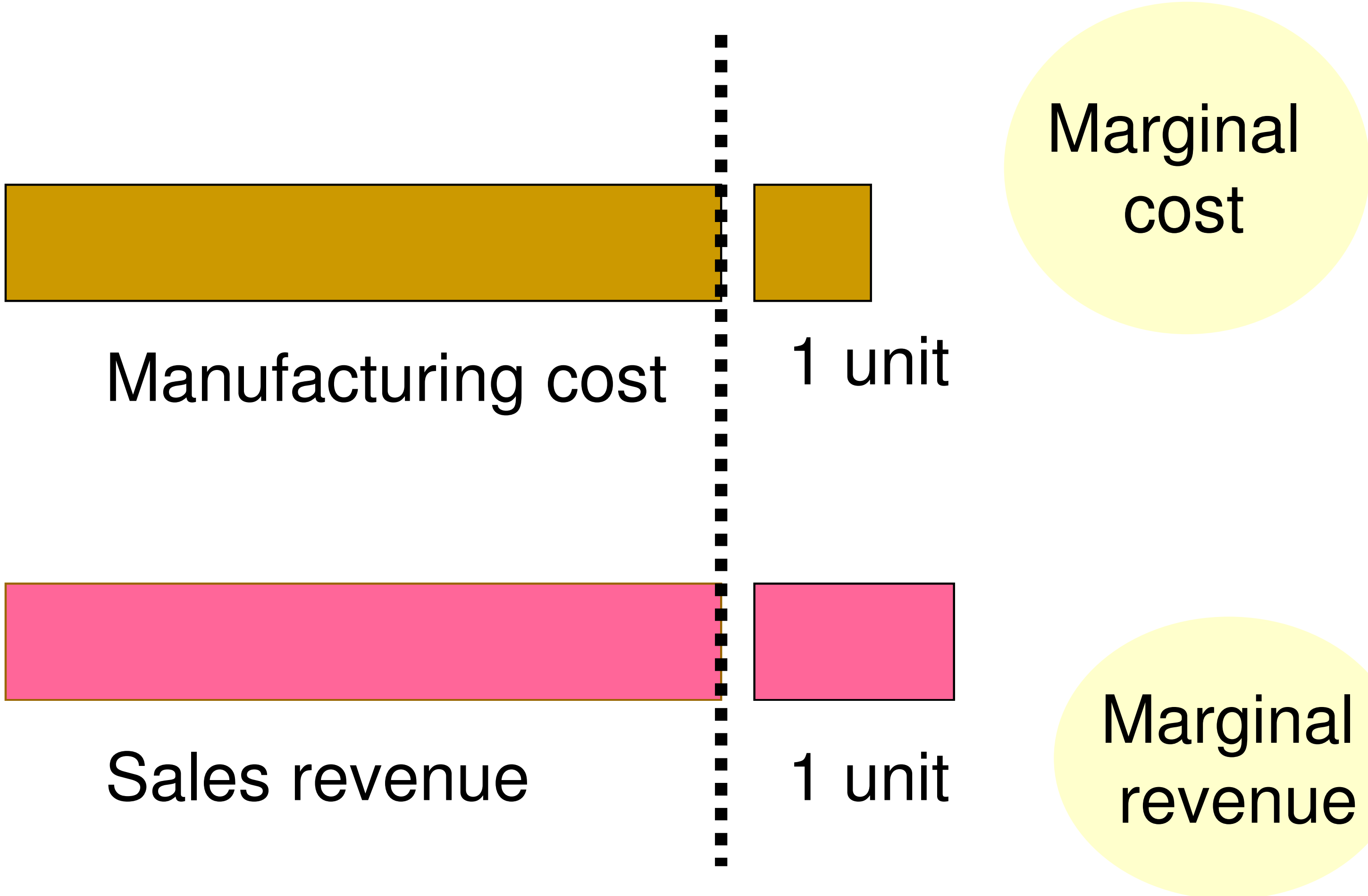


Principle 2: Only the cost (resource) difference among alternatives counts

Option	Monthly Fuel Cost	Monthly Maintenance	Cash outlay at signing	Monthly payment	Salvage Value at end of year 3
Buy	$960	$550	$6,500	$350	$9,000
Lease	$960	$550	$2,400	$550	0

Irrelevant items in decision making (identical in both cases)

Principle 3: Marginal (unit) revenue has to exceed marginal cost, in order to increase production



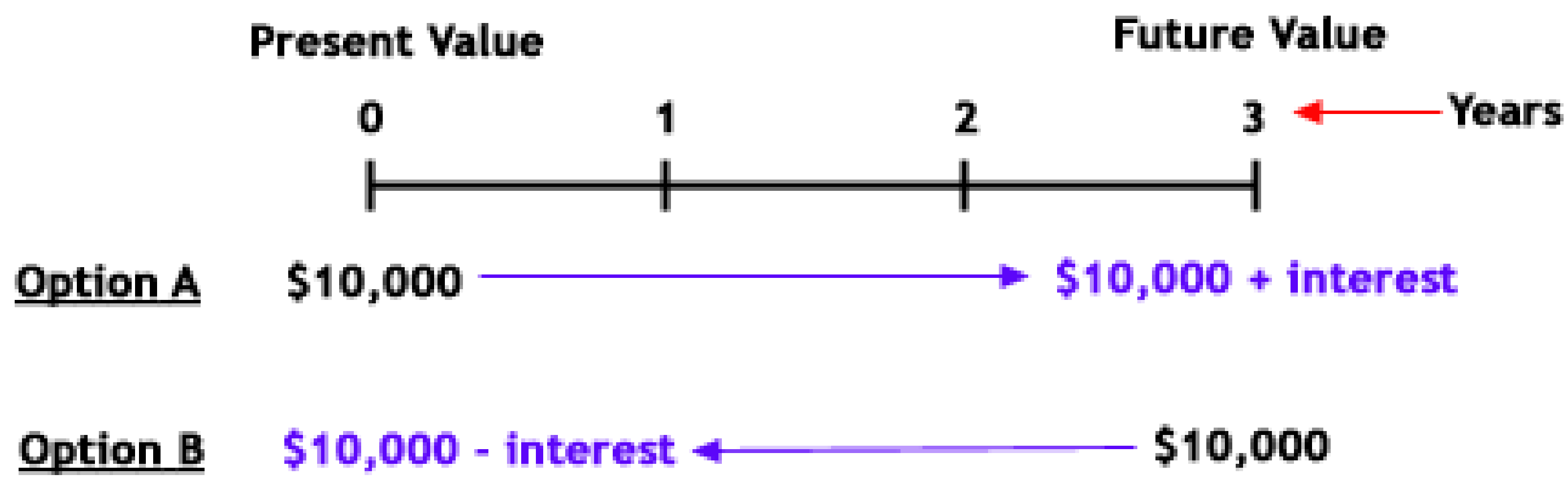
Principle 4: Additional risk is not taken without a suitable expected additional return

Investment Class	Potential Risk	Expected Return
Savings account (cash)	Low/None	1.5%
Bond (debt)	Moderate	4.8%
Stock (equity)	High	11.5%

A simple illustrative example. Note that all investments imply some risk: portfolio management is a key issue in finance

Time Value of Money (TVM)

- Interest: The Cost of Money
- Interest Rate and Inflation
- Present Value vs Future Value
- Cash Flow Diagram



Decision Dilemma—Take a Lump Sum or Annual Installments

- A couple won a lottery.
- They had to choose between a single lump sum \$104 million, or \$198 million paid out over 25 years (or \$7.92 million per year).
- The winning couple opted for the lump sum.
- Did they make the right choice? What basis do we make such an economic comparison?

Decision Dilemma—Take a Lump Sum or Annual Installments

	Option A (Lump Sum)	Option B (Installment Plan)
0	$104 M	$7.92 M
1		$7.92 M
2		$7.92 M
3		$7.92 M
⋮		⋮
24		$7.92 M

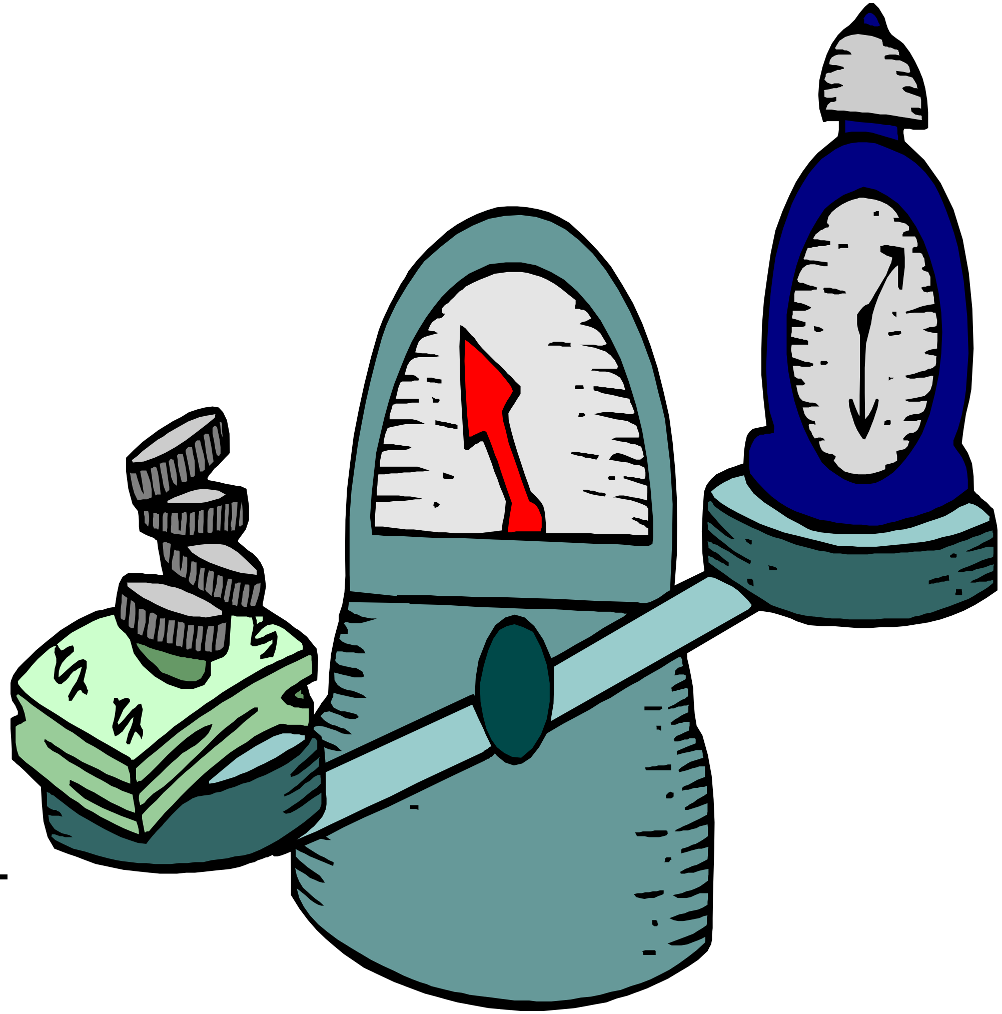
Time Value of Money

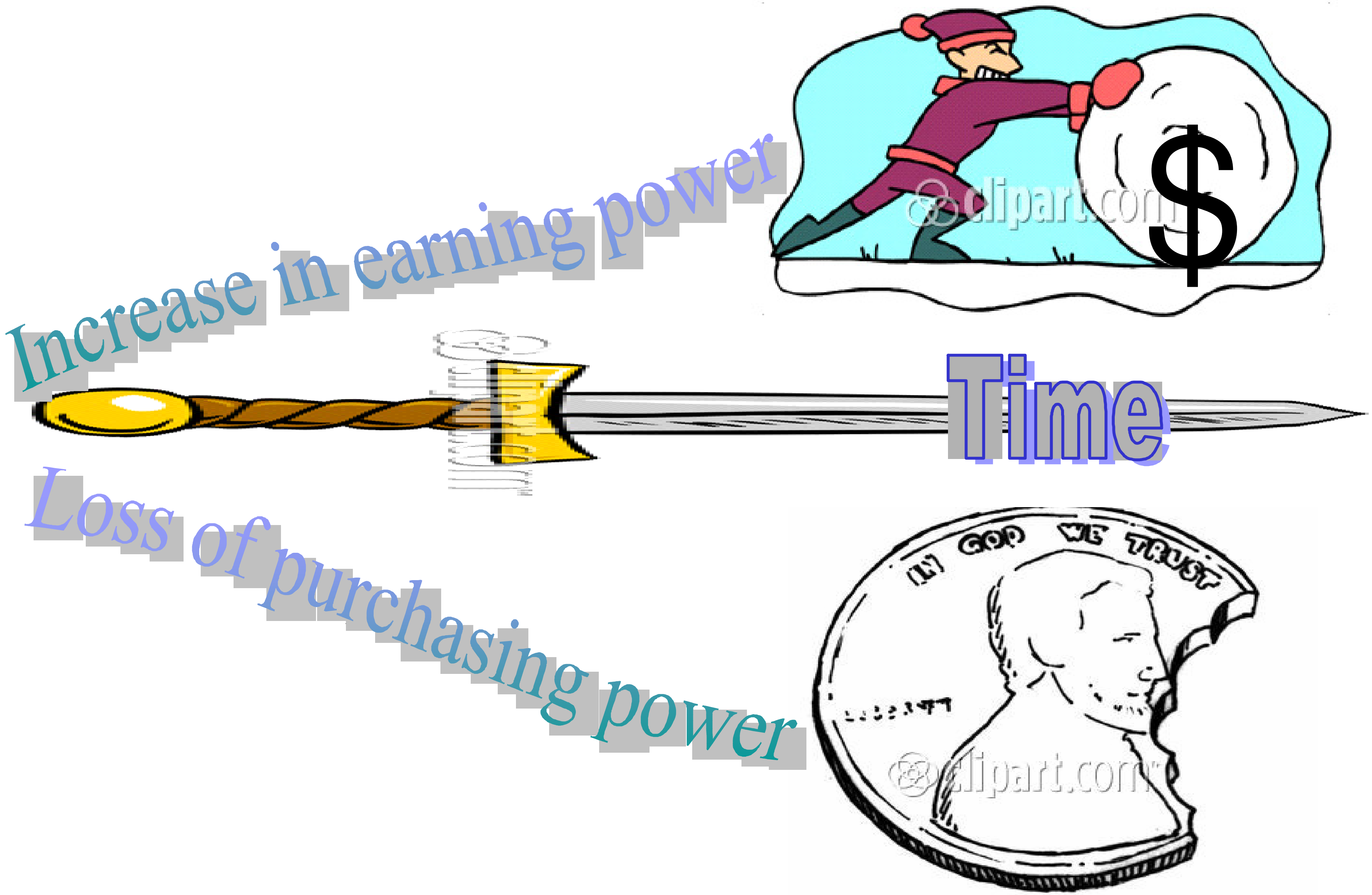
What Do We Need to Know?

- To make such comparisons (the lottery decision problem), we must be able to compare the value of money at different point in time
- To do this, we need to develop a method for reducing a sequence of benefits and costs to a single point in time. Then, we will make our comparisons on that basis

Time Value of Money

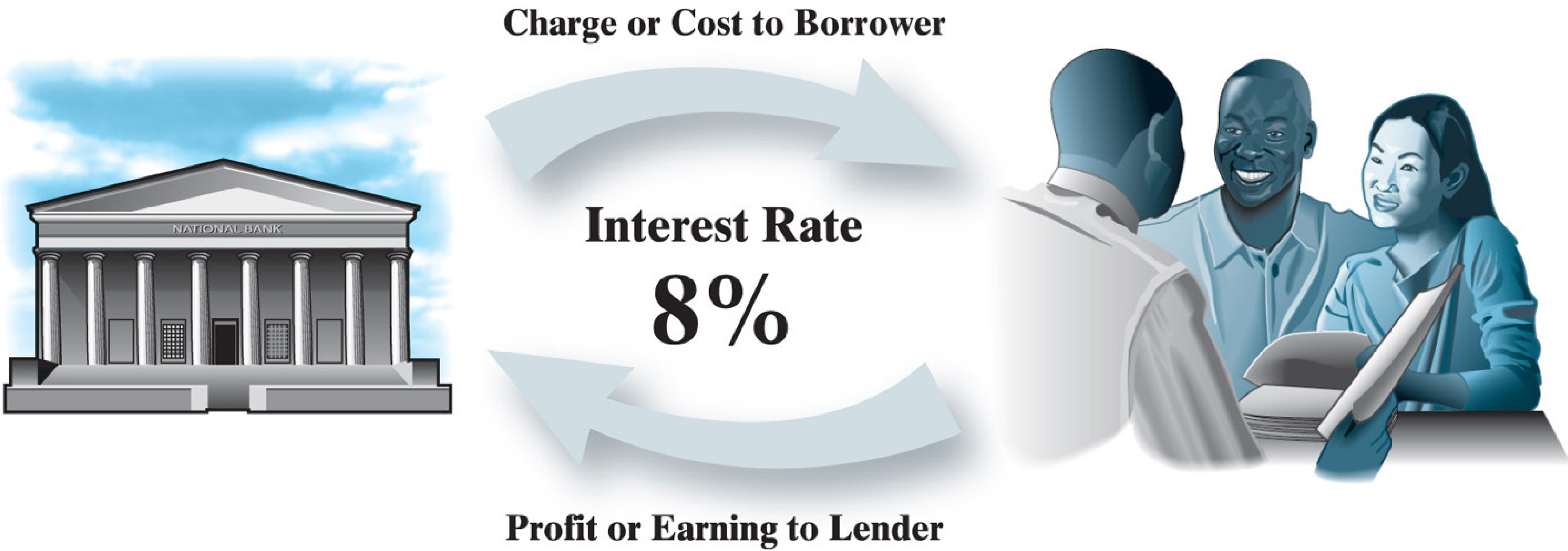
- Money has a time value because it can earn more money over time (earning power).
- Money has a time value because its purchasing power changes over time (inflation).
- Time value of money is measured in terms of interest rate.
- Interest is the cost of money -- a cost to the borrower and an earning to the lender





* This a two-edged sword whereby earning grows, but purchasing power decreases (due to inflation), as time goes by.

The Interest Rate



Delaying Consumption

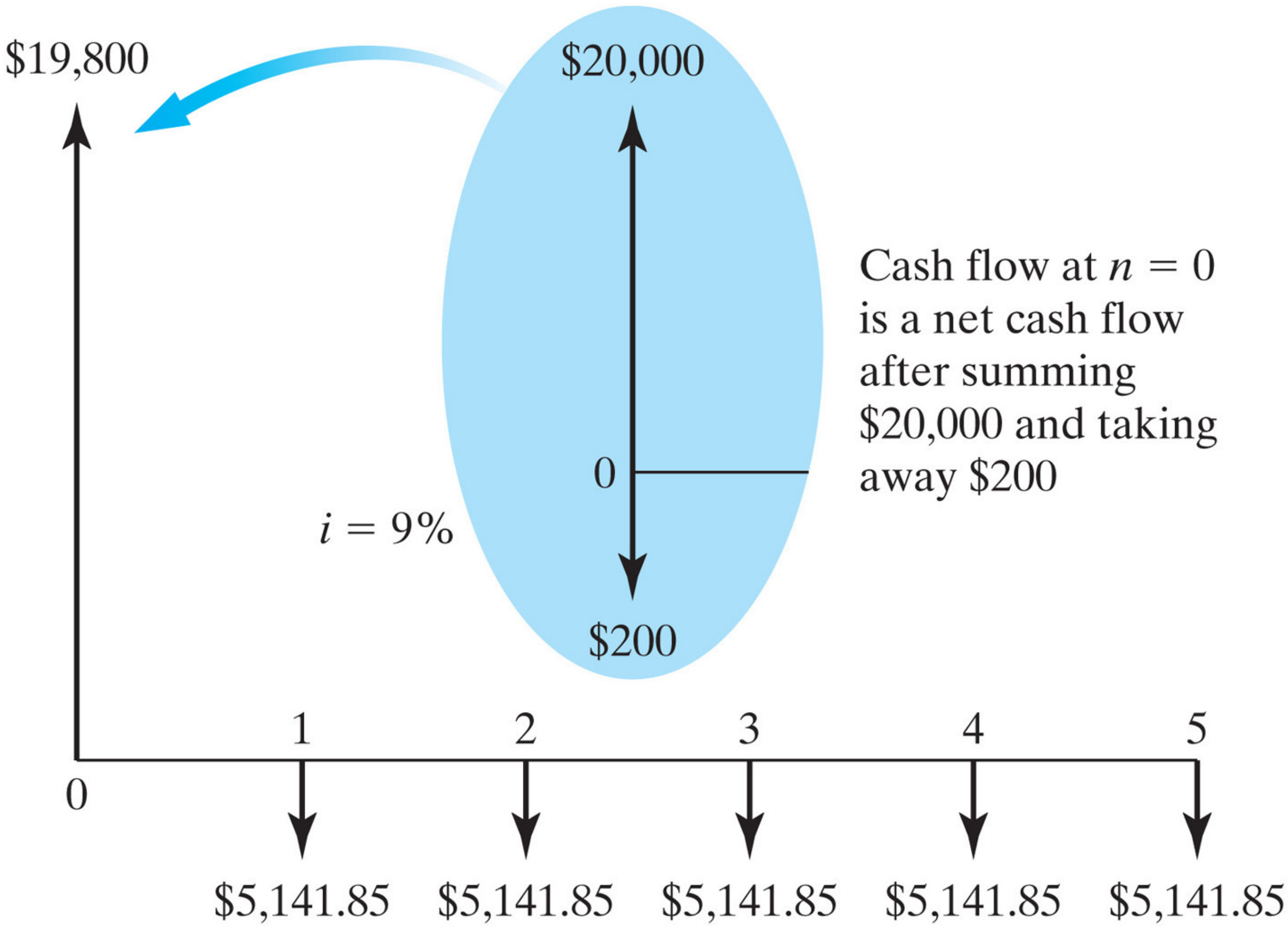
	Account Value	Cost of Refrigerator
		
Case 1: Inflation exceeds earning power	N = 0 $100 N = 1 $106 (earning rate =6%)	N = 0 $100 N = 1 $108 (inflation rate = 8%)
Case 2: Earning power exceeds inflation	N = 0 $100 N = 1 $106 (earning rate =6%)	N = 0 $100 N = 1 $104 (inflation rate = 4%)

Which Repayment Plan?

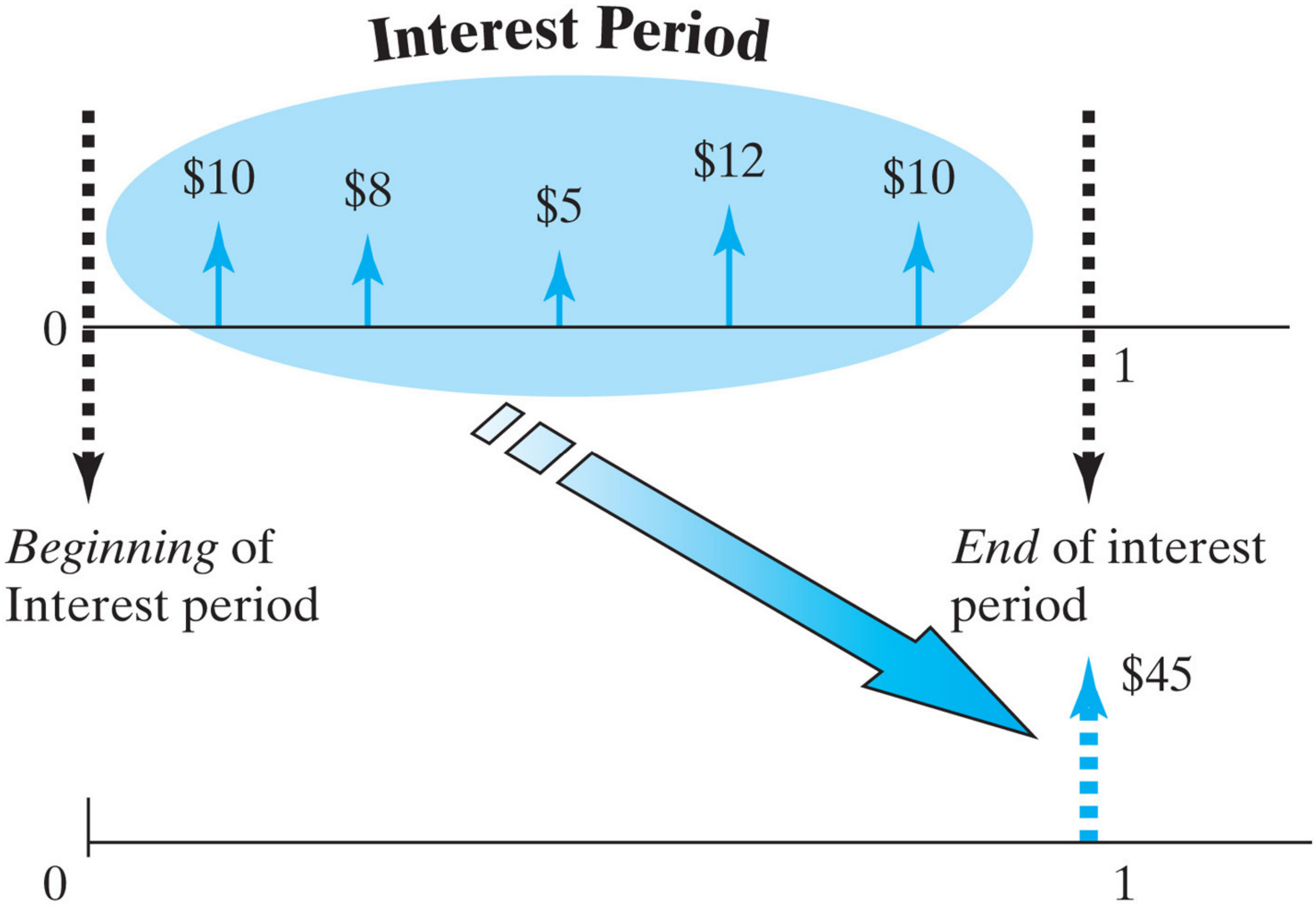
End of Year	Receipts	Payments	
		Plan 1	Plan 2
Year 0	$20,000.00	$200.00	$200.00
Year 1		5,141.85	0
Year 2		5,141.85	0
Year 3		5,141.85	0
Year 4		5,141.85	0
Year 5		5,141.85	30,772.48
The amount of loan = $20,000, origination fee = $200, interest rate = 9% APR (annual percentage rate)			

Cash Flow Diagram

Represent time by a horizontal line marked off with the number of interest periods specified. Cash flow diagrams give a convenient summary of all the important elements of a problem.



End-of-Period Convention



Elements of Transactions involve Interest (terminology)

1. Initial amount of money in transactions involving debt or investments is called the principal (P).
2. The interest rate (*i*) measures the cost or price of money and is expressed as a percentage per period of time.
3. A period of time, called the interest period (*n*), determines how frequently interest is calculated.
4. A specified length of time marks the duration of the transactions and thereby establishes a certain number of interest periods (*N*).
5. A plan for receipts or disbursements (*An*) that yields a particular cash flow pattern over a specified length of time. [monthly equal payment]
6. A future amount of money (*F*) results from the cumulative effects of the interest rate over a number of interest periods.

Interest Calculations

- Simple interest: the practice of charging an interest rate only to an initial sum (principal amount)
- Compound interest: the practice of charging an interest rate to an initial sum and to any previously accumulated interest that has not been withdrawn

Simple Interest

- *P* = Principal amount
- *i* = Interest rate
- *N* = Number of interest periods
- Example:
  - *P* = $1,000
  - *i* = 8%
  - *N* = 3 years

End of Year	Beginning Balance	Interest earned	Ending Balance
0			$1,000
1	$1,000	$80	$1,080
2	$1,080	$80	$1,160
3	$1,160	$80	$1,240

Simple Interest Formula

$$F = P + (iP)N$$

where

P = Principal amount

i = simple interest rate

N = number of interest periods

F = total amount accumulated at the end of period N

$$F = \$1,000 + (0.08)(\$1,000)(3)$$
$$= \$1,240$$

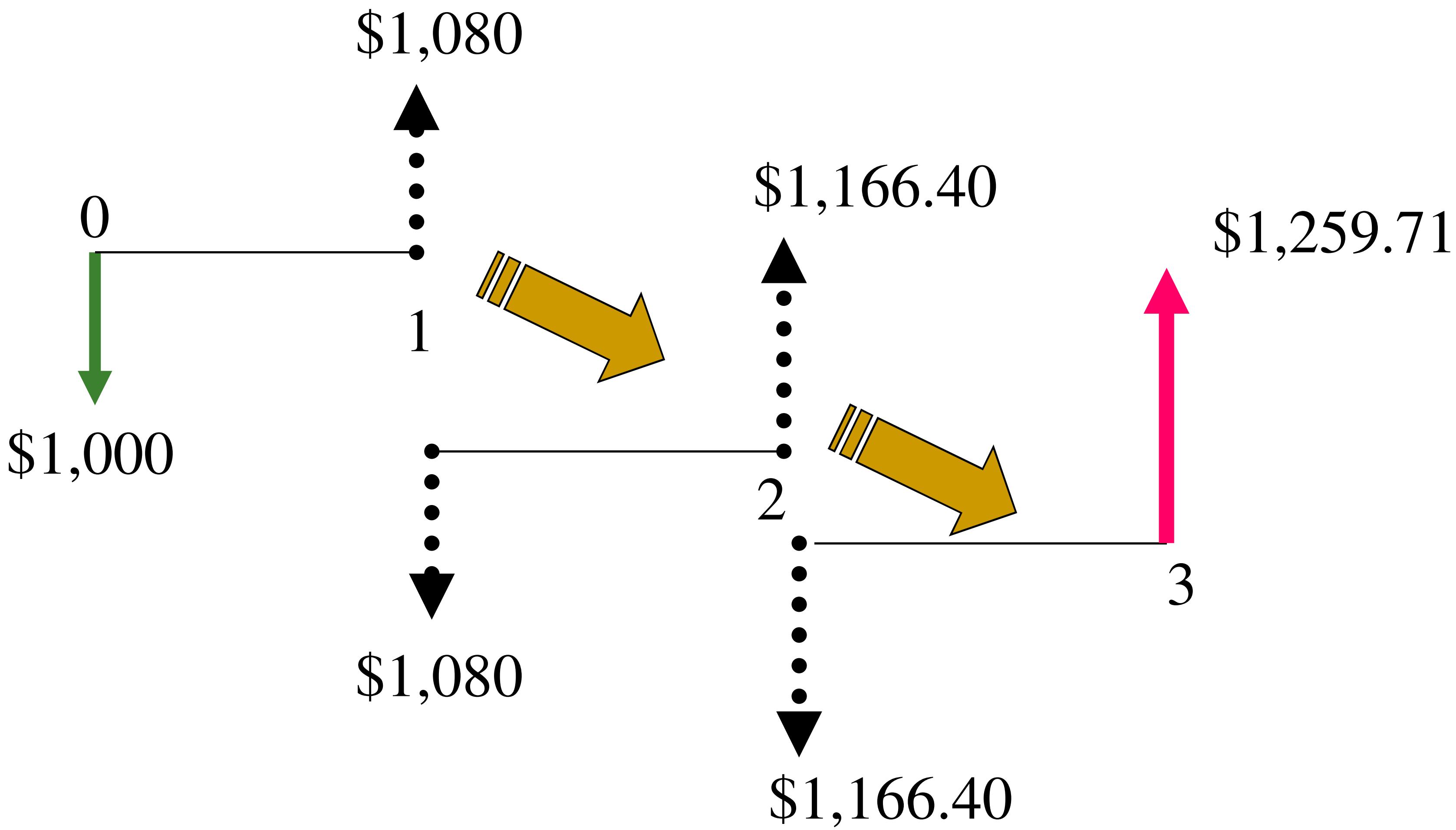
Compound Interest

The practice of charging an interest rate to an initial sum and to any previously accumulated interest that has not been withdrawn.

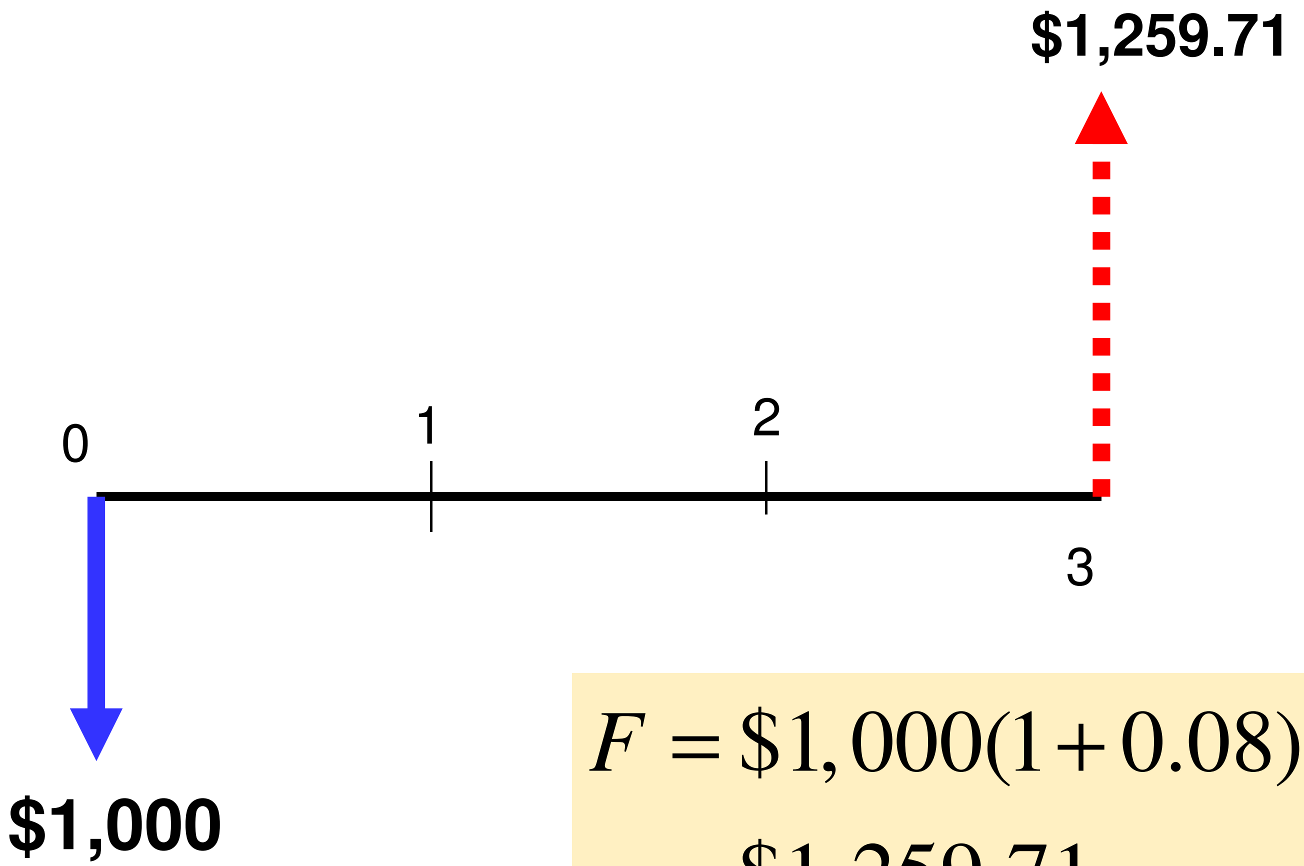
- *P* = Principal amount
- *i* = Interest rate
- *N* = Number of interest periods
- Example:
  - *P* = $1,000
  - *i* = 8%
  - *N* = 3 years

End of Year	Beginning Balance	Interest earned	Ending Balance
0			$1,000
1	$1,000	$80	$1,080
2	$1,080	$86.40	$1,166.40
3	$1,166.40	$93.31	$1,259.71

Compounding Process



Cash Flow Diagram



$$F = \$1,000(1+0.08)^3$$
$$= \$1,259.71$$

Compound Interest Formula

$$n = 0 : P$$

$$n = 1 : F_1 = P(1+i)$$

$$n = 2 : F_2 = F_1(1+i) = P(1+i)^2$$

$$\vdots$$

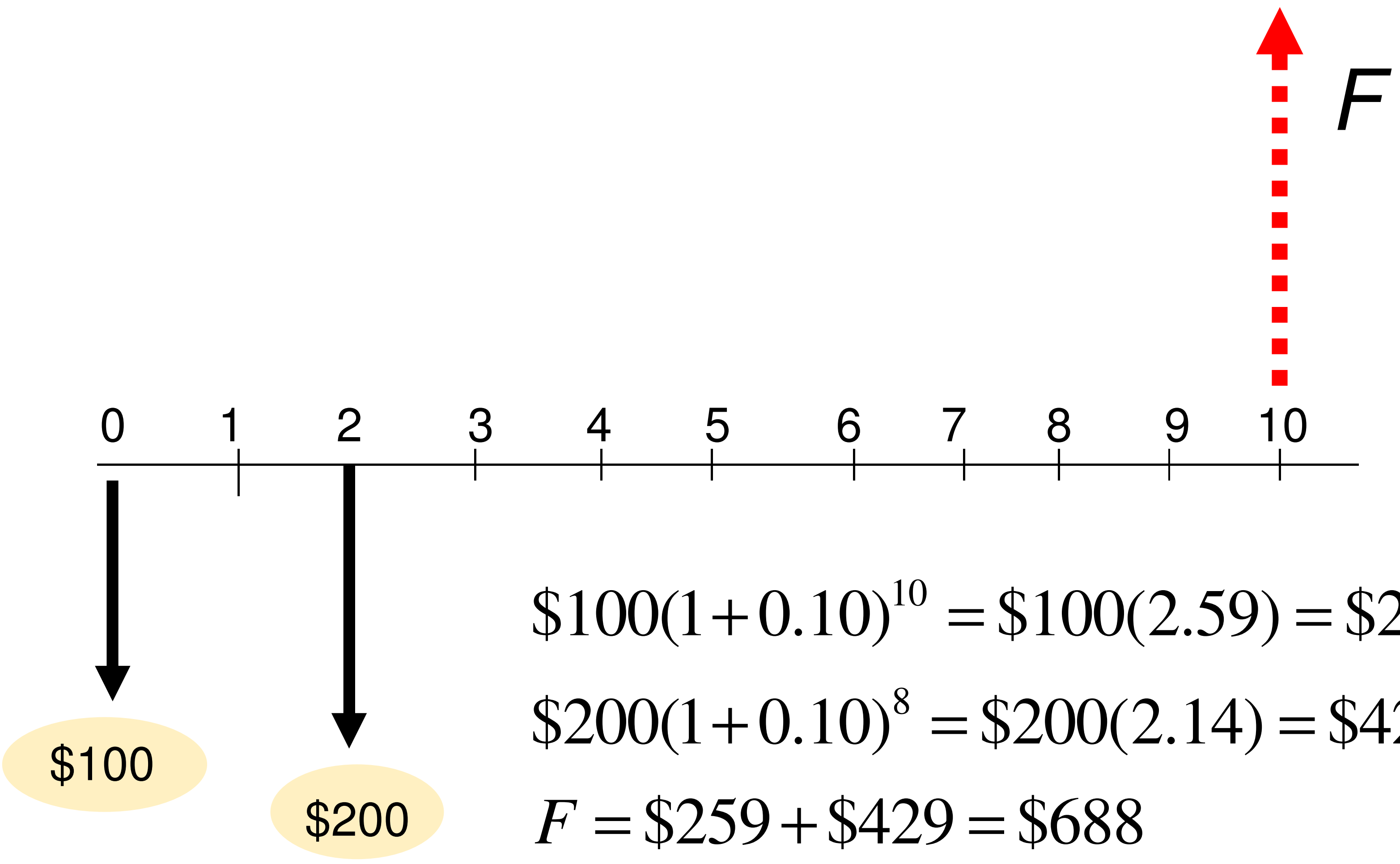
$$n = N : \boxed{F = P(1+i)^N}$$

Practice Problem (1)

- Problem Statement

  If you deposit \$100 now ($n = 0$) and \$200 two years from now ($n = 2$) in a savings account that pays 10% interest, how much would you have at the end of year 10?

Solution



$$\$100(1+0.10)^{10} = \$100(2.59) = \$259$$

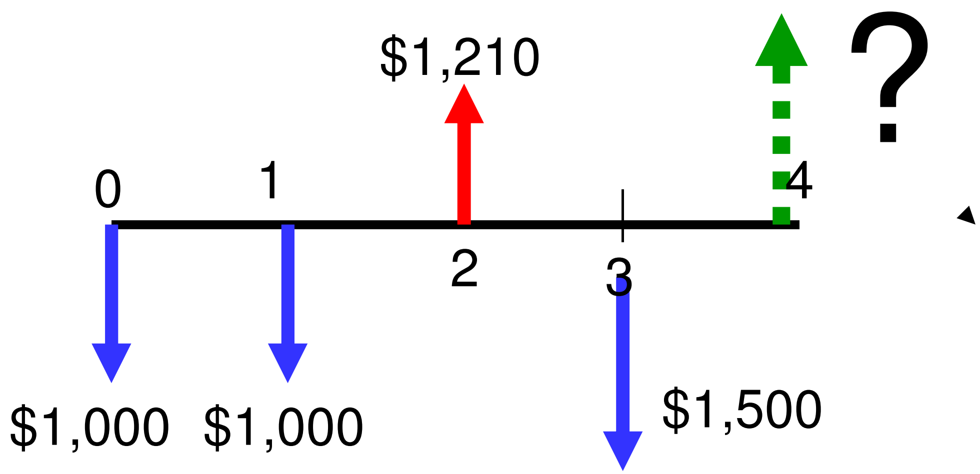
$$\$200(1+0.10)^{8} = \$200(2.14) = \$429$$

$$F = \$259 + \$429 = \$688$$

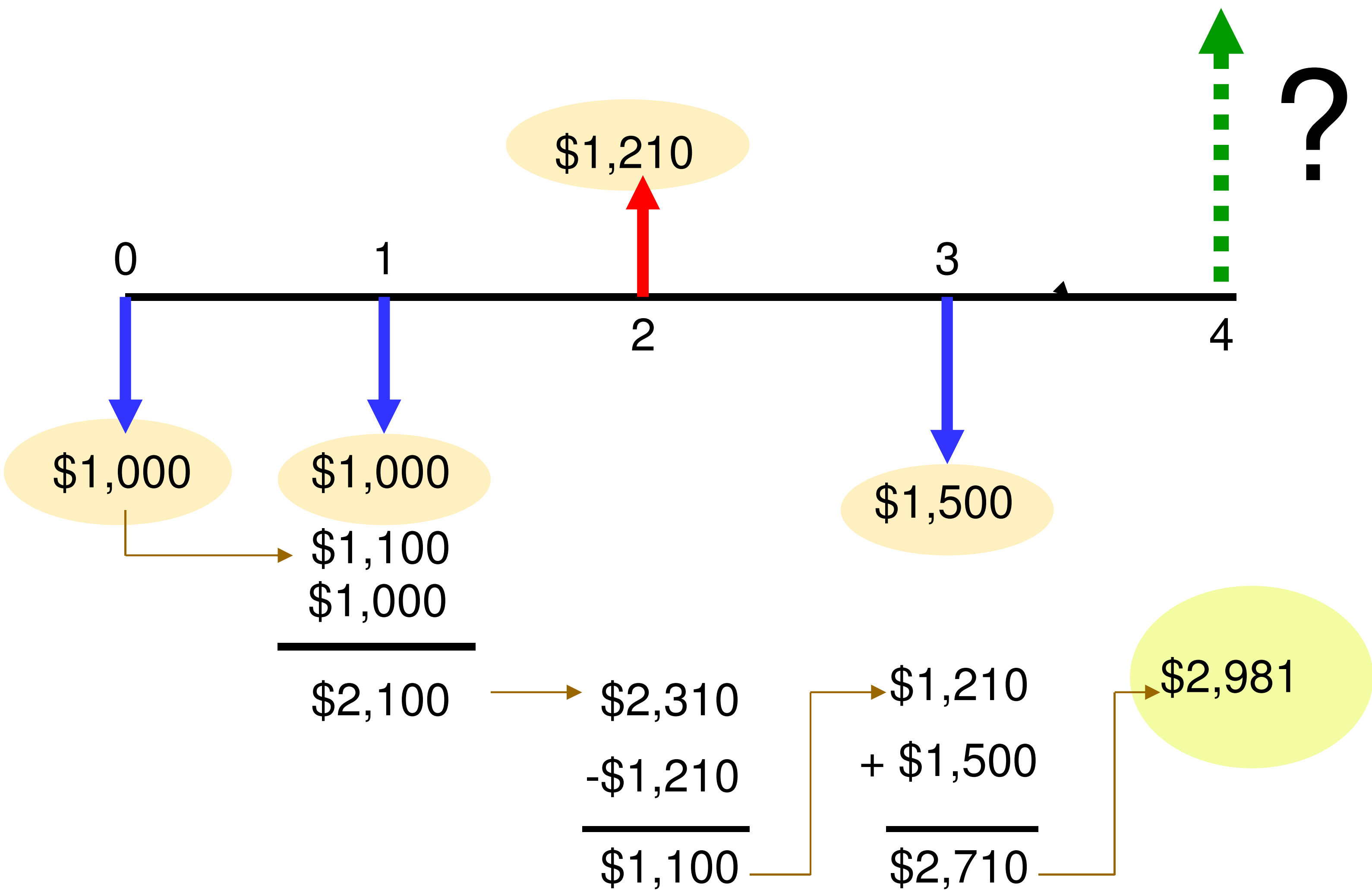
Practice problem (2)

- Problem Statement

  Consider the following sequence of deposits and withdrawals over a period of 4 years. If you earn 10% interest, what would be the balance at the end of 4 years?



Cash Flow Diagram



Solution

End of Period	Beginning balance	Deposit made	Withdraw	Ending balance
$n = 0$	0	\$1,000	0	\$1,000
$n = 1$	\$1,000(1 + 0.10) =\$1,100	\$1,000	0	\$2,100
$n = 2$	\$2,100(1 + 0.10) =\$2,310	0	\$1,210	\$1,100
$n = 3$	\$1,100(1 + 0.10) =\$1,210	\$1,500	0	\$2,710
$n = 4$	\$2,710(1 + 0.10) =\$2,981	0	0	\$2,981

Further Reading

- Engineering economics -- Wikipedia,
  - http://en.wikipedia.org/wiki/Engineering_economics
- Time value of money -- Wikipedia,
  - http://en.wikipedia.org/wiki/Time_value_of_money
- Kreith, F. and Goswami, D. Y. (eds.), 2005. *The CRC Handbook of Mechanical Engineering*, 2nd ed., Chapter 17 Engineering Economics and Project Management, CRC Press, Boca Raton, FL. [621 C9][book via ENGnetBASE]