Industrial Robotics

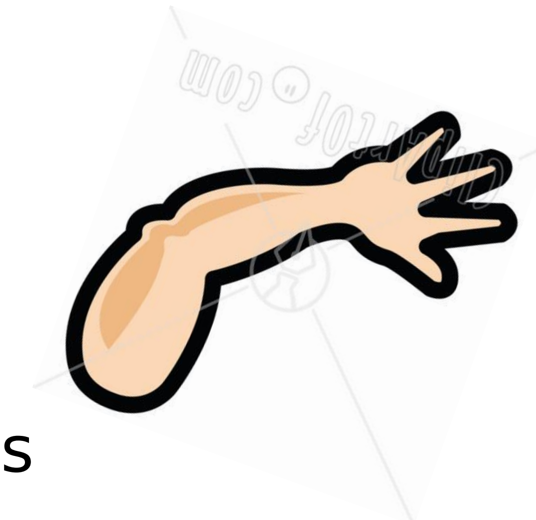
Sections:

1. Robot Anatomy
2. Robot Control Systems
3. End Effectors
4. Industrial Robot Applications
5. Robot Programming

- Bharat Dogra

Industrial Robot Defined

A general-purpose, programmable machine possessing certain anthropomorphic characteristics



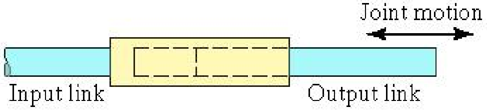
- Hazardous work environments
- Repetitive work cycle
- Consistency and accuracy
- Difficult handling task for humans
- Multishift operations
- Reprogrammable, flexible
- Interfaced to other computer systems

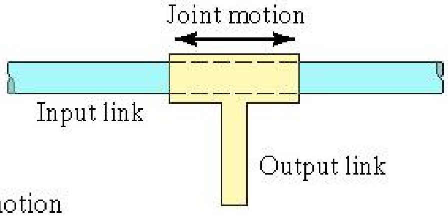
Robot Anatomy

- Manipulator consists of joints and links
  - Joints provide relative motion
  - Links are rigid members between joints
  - Various joint types: linear and rotary
  - Each joint provides a “degree-of-freedom”
  - Most robots possess five or six degrees-of-freedom
- Robot manipulator consists of two sections:
  - Body-and-arm – for positioning of objects in the robot's work volume

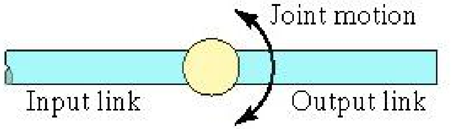
Manipulator Joints

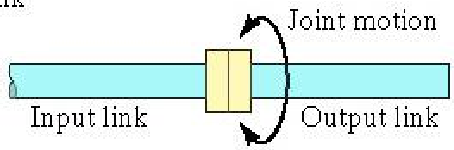
- Translational motion
  - Linear joint (type L)
  - Orthogonal joint (type O)

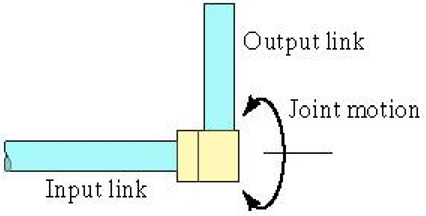




- Rotary motion
  - Rotational joint (type R)
  - Twisting joint (type T)
  - Revolving joint (type V)







Joint Notation Scheme

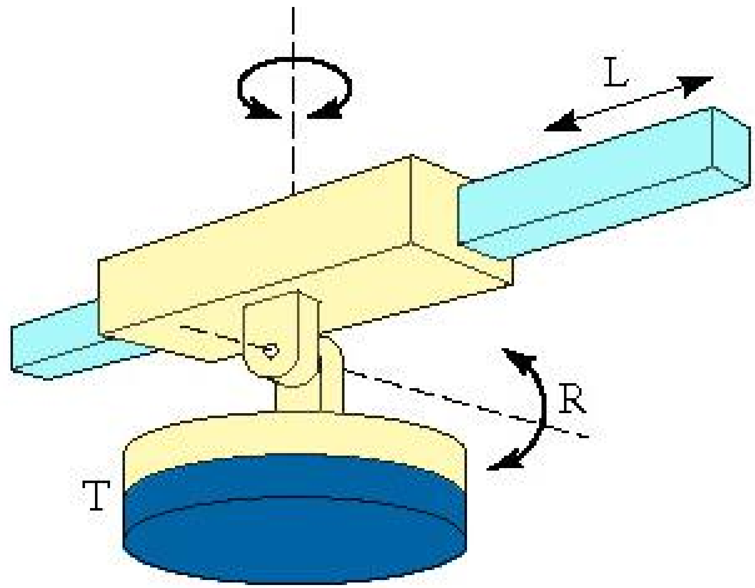
- Uses the joint symbols (L, O, R, T, V) to designate joint types used to construct robot manipulator
- Separates body-and-arm assembly from wrist assembly using a colon (:)

- Example: TLR : TR

- Common body-and-arm configurations …

Polar Coordinate Body-and-Arm Assembly

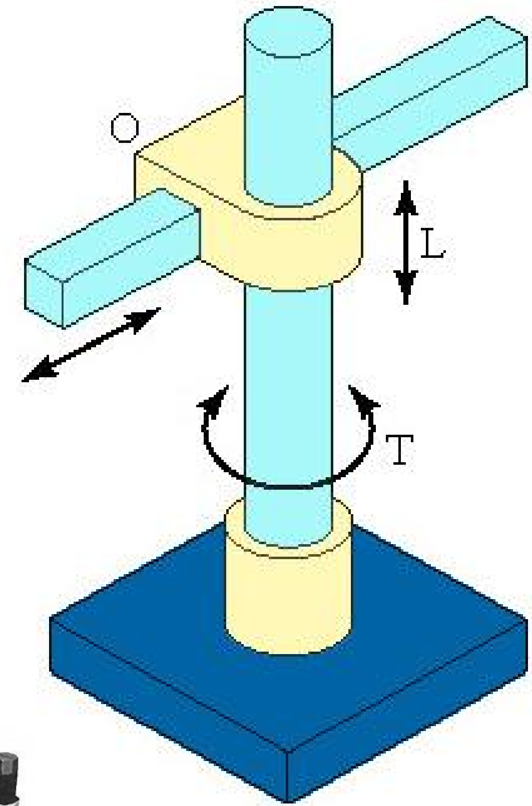
- Notation TRL:



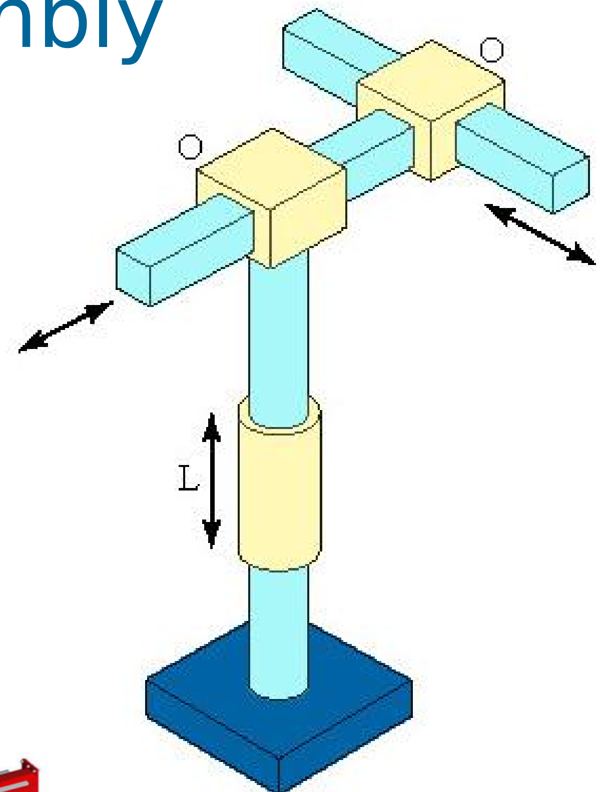
- Consists of a sliding arm (L joint) actuated relative to the body, which can rotate about both a vertical axis (T joint) and horizontal axis (R joint)

Cylindrical Body-and-Arm Assembly

- Notation TLO:
- Consists of a vertical column, relative to which an arm assembly is moved up or down
- The arm can be mov
  out relative to the co

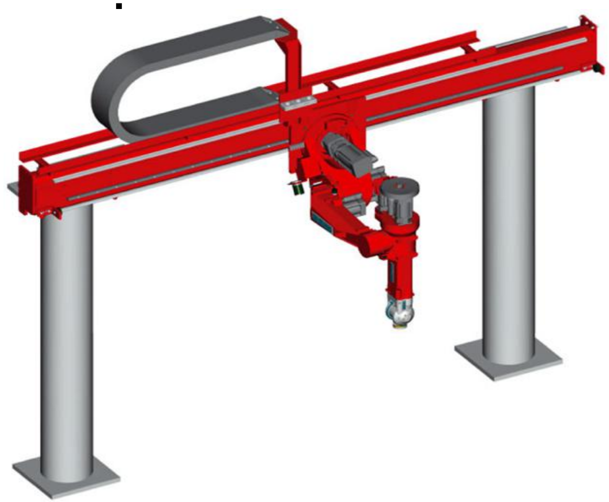


Cartesian Coordinate Body-and-Arm Assembly



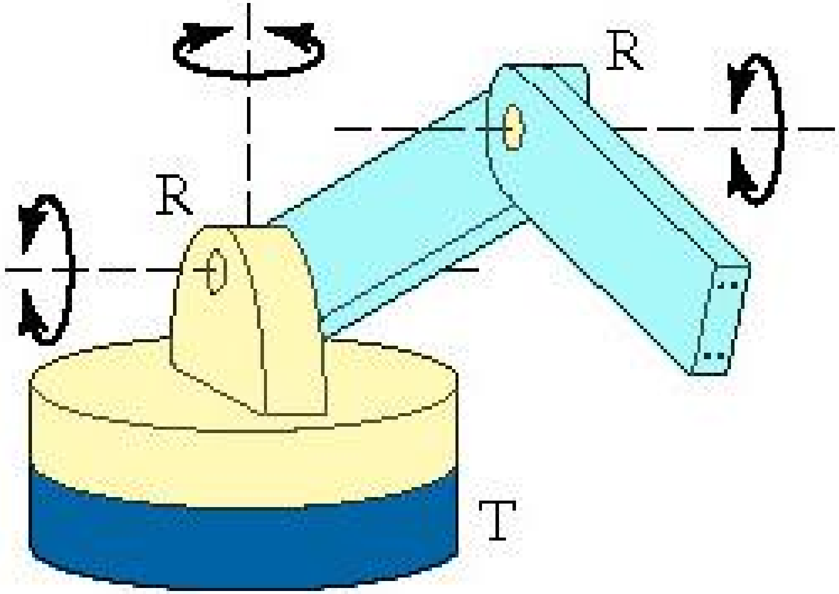
- Notation LOO:

- Consists of three sliding joints, two of which are orthogonal
- Other names include rectilinear robot robot



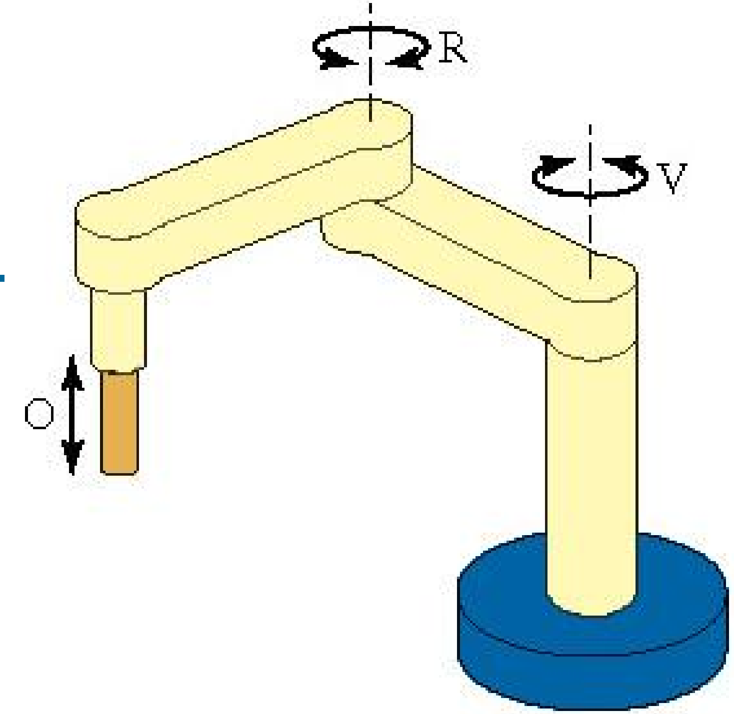
Jointed-Arm Robot

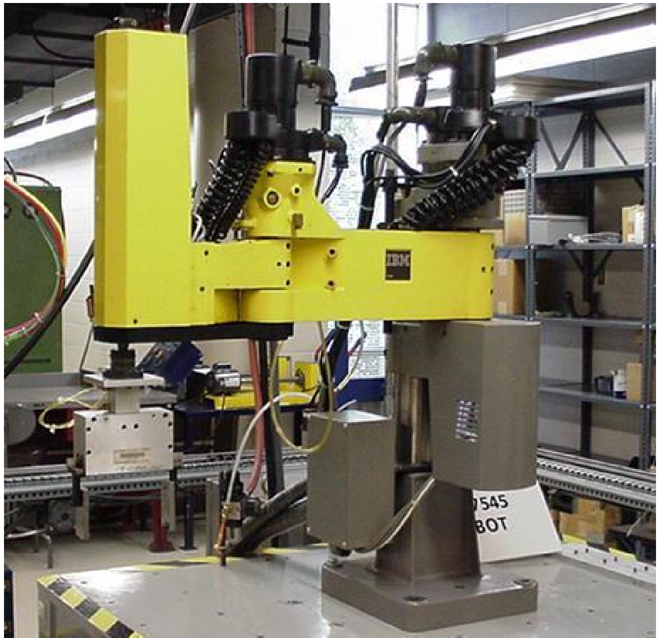
- Notation TRR:



SCARA Robot

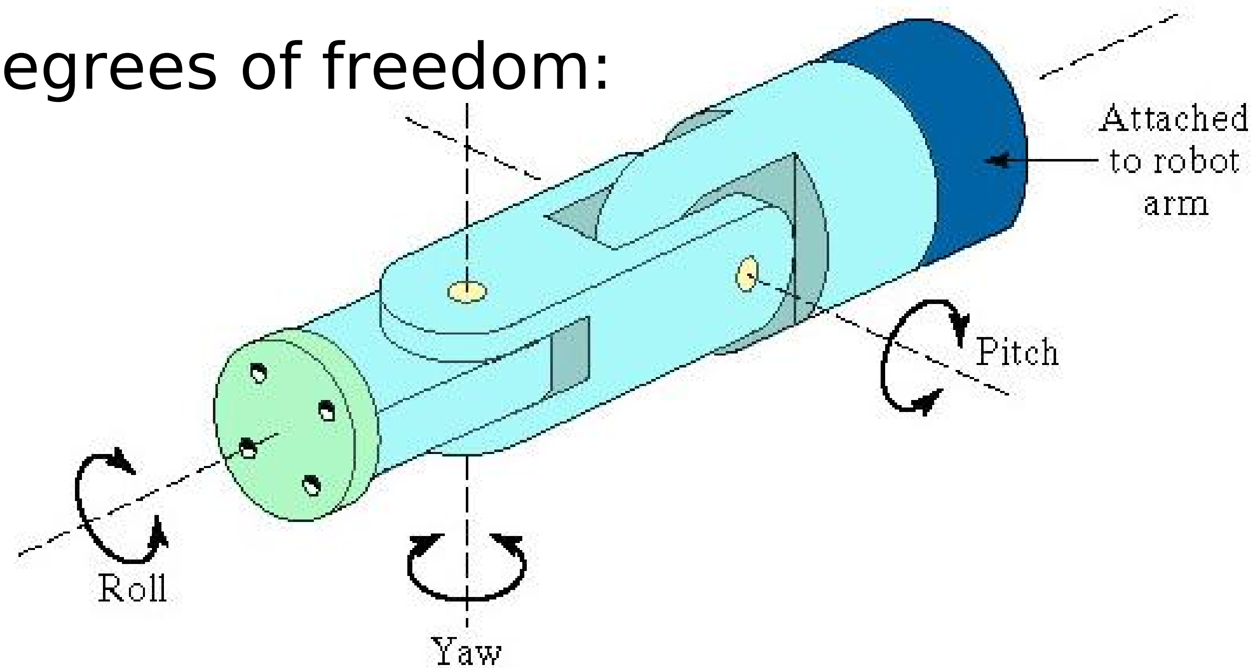
- Notation VRO
- SCARA stands for Selectively Compliant Assembly Robot Arm
- Similar to jointed-arm robot except that vertical axes are used for shoulder and elbow joints to be compliant in horizontal direction for vertical insertion tasks





Wrist Configurations

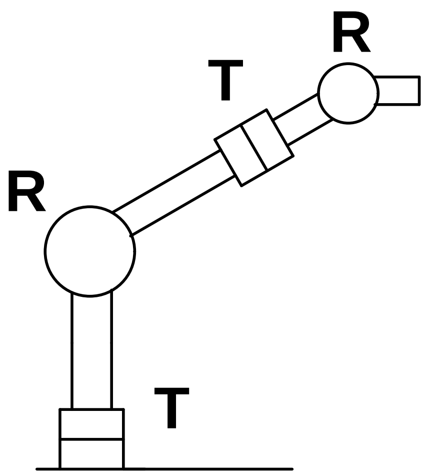
- Wrist assembly is attached to end-of-arm
- End effector is attached to wrist assembly
- Function of wrist assembly is to orient end effector
  - Body-and-arm determines global position of end effector
- Two or three degrees of freedom:
  - Roll
  - Pitch
  - Yaw
- Notation :RRT



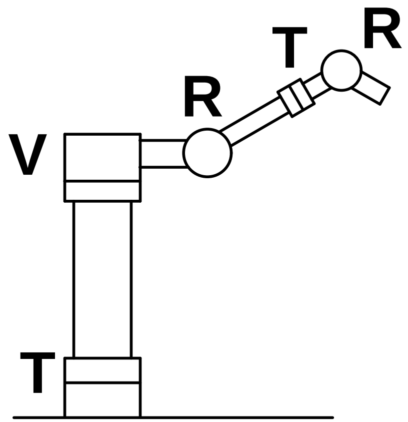
Example

- Sketch following manipulator configurations
- (a) TRT:R, (b) TVR:TR, (c) RR:T.

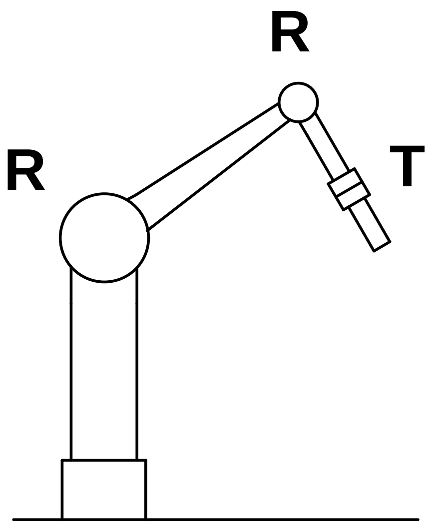
Solution:



(a) TRT:R

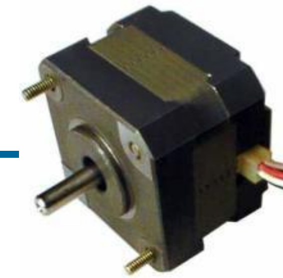


(b) TVR:TR



(c) RR:T

Joint Drive Systems



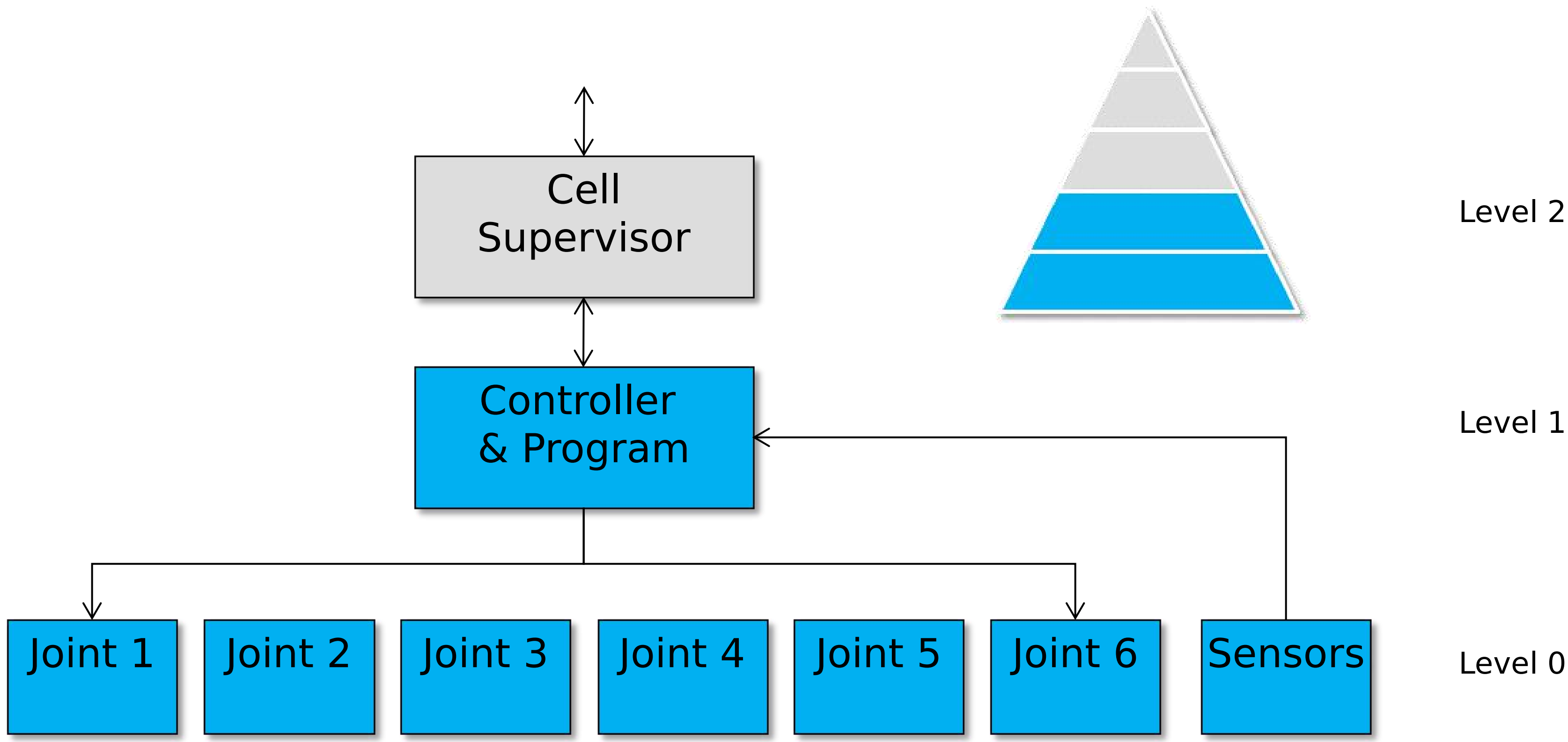
- Electric
  - Uses electric motors to actuate individual joints
  - Preferred drive system in today's robots

- Hydraulic
  - Uses hydraulic pistons and rotary vane actuators
  - Noted for their high power and lift capacity
- Pneumatic
  - Typically limited to smaller robots and simple material transfer applications

Robot Control Systems

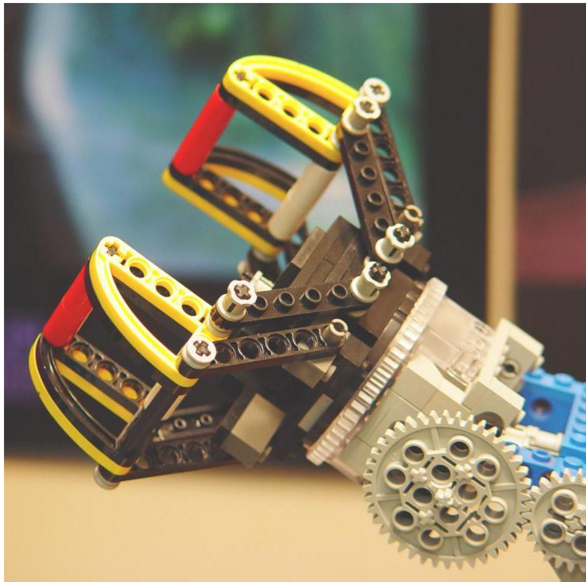
- **Limited sequence control** – pick-and-place operations using mechanical stops to set positions
- **Playback with point-to-point control** – records work cycle as a sequence of points, then plays back the sequence during program execution
- **Playback with continuous path control** – greater memory capacity and/or interpolation capability to execute paths (in addition to points)
- **Intelligent control** – exhibits behavior that makes it seem intelligent, e.g., responds to sensor inputs, makes decisions, communicates with humans

Robot Control System

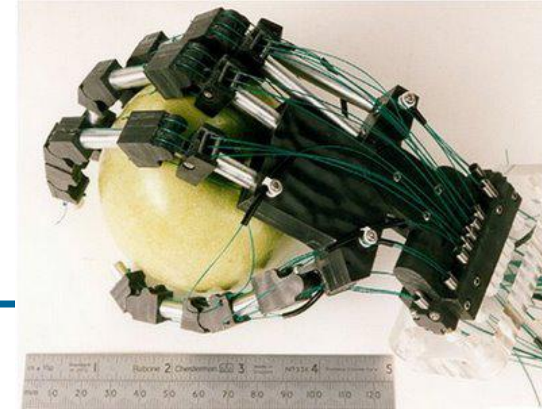


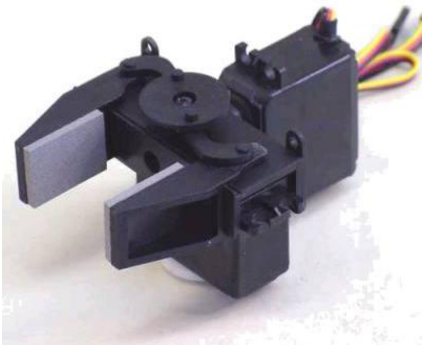
End Effectors

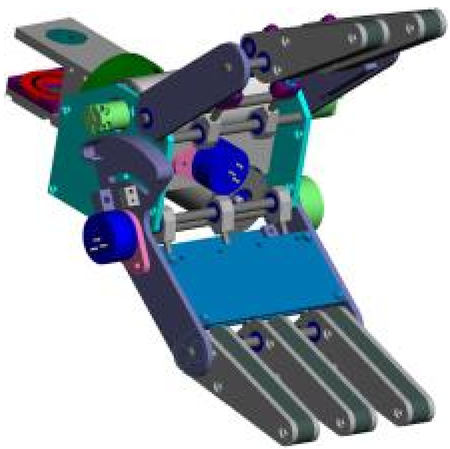
- The special tooling for a robot that enables it to perform a specific task
- Two types:
  - Grippers – to grasp and manipulate objects (e.g., parts) during work cycle
  - Tools – to perform a process, e.g., spot welding, spray painting



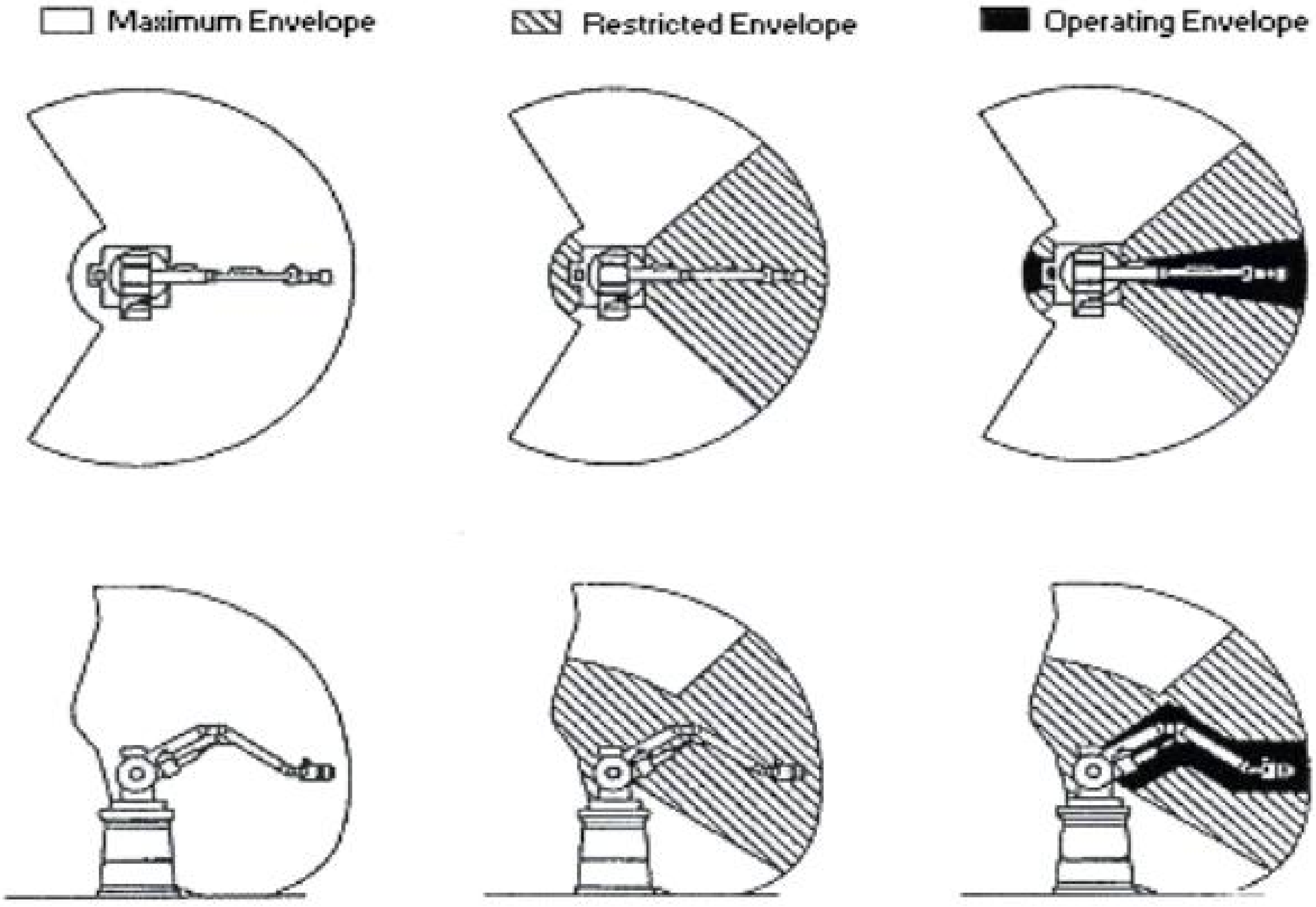
Grippers and Tools





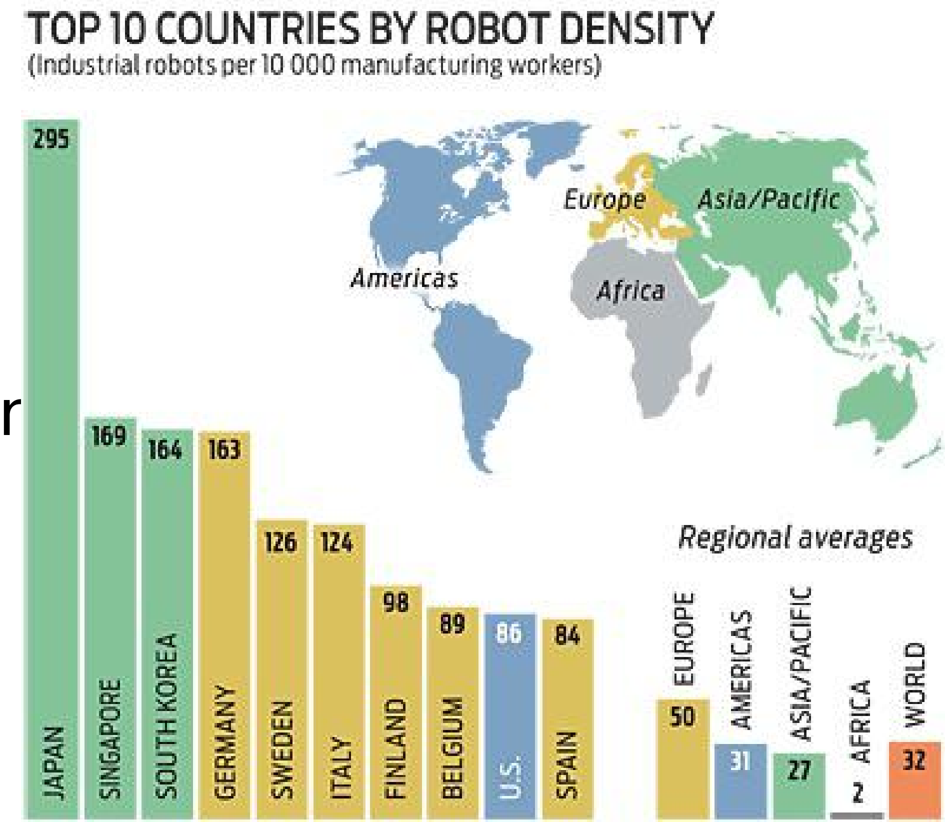


Working Envelope



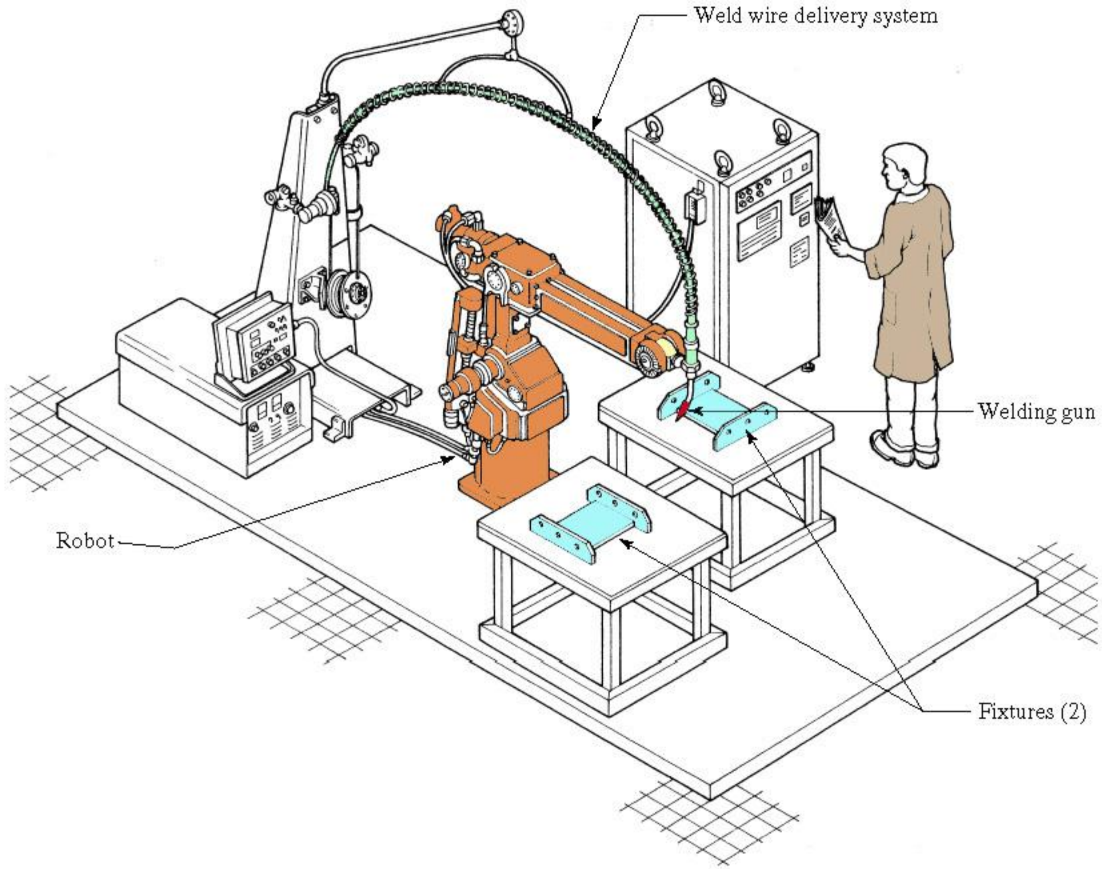
Industrial Robot Applications

1. Material handling applications
   - Material transfer – pick-and-place, palletizing
   - Machine loading and/or unloading
2. Processing operations
   - Welding
   - Spray coating
   - Cutting and grinding
3. Assembly and inspection



Robotic Arc-Welding Cell

- Robot performs flux-cored arc welding (FCAW) operation at one workstation while fitter changes parts at the other workstation

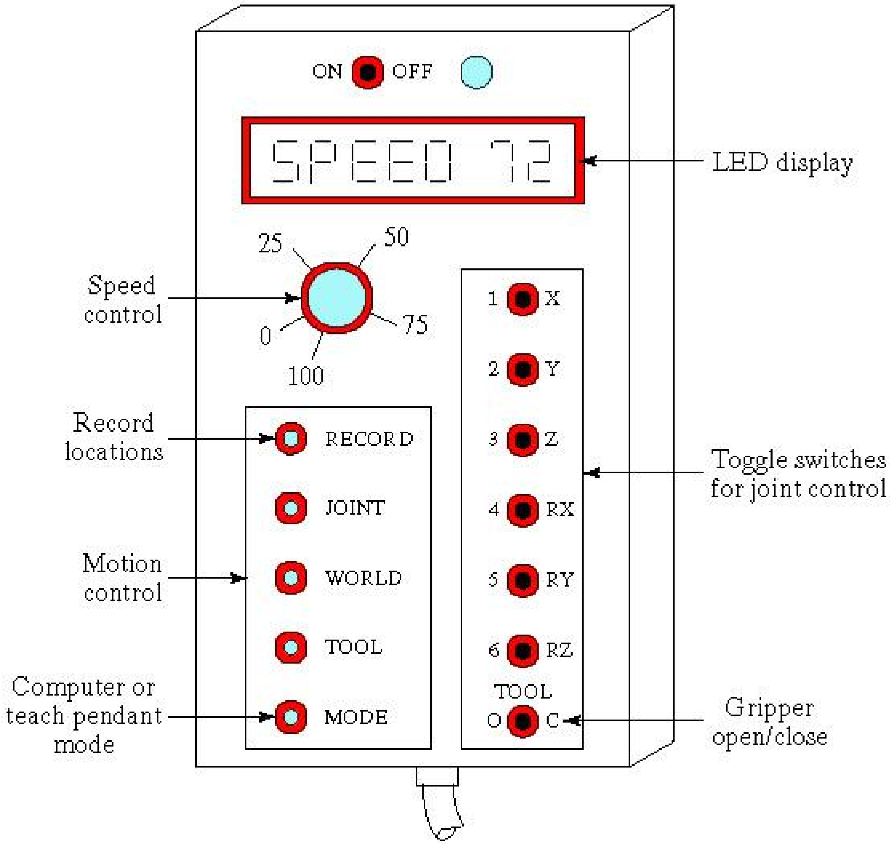


Robot Programming

- Leadthrough programming
  - Work cycle is taught to robot by moving the manipulator through the required motion cycle and simultaneously entering the program into controller memory for later playback
- Robot programming languages
  - Textual programming language to enter commands into robot controller
- Simulation and off-line programming
  - Program is prepared at a remote computer terminal and downloaded to robot controller for execution without need for leadthrough

Leadthrough Programming

1. Powered leadthrough
   - Common for point-to-point robots
   - Uses teach pendant
2. Manual leadthrough
   - Convenient for continuous path control robots
   - Human programmer physical moves manipulator

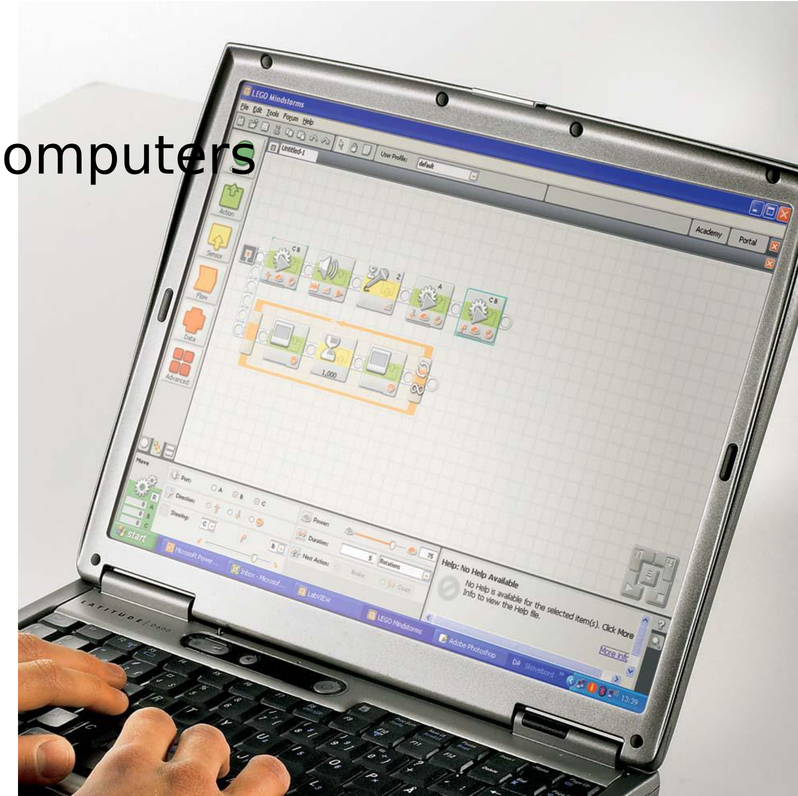


Leadthrough Programming Advantages

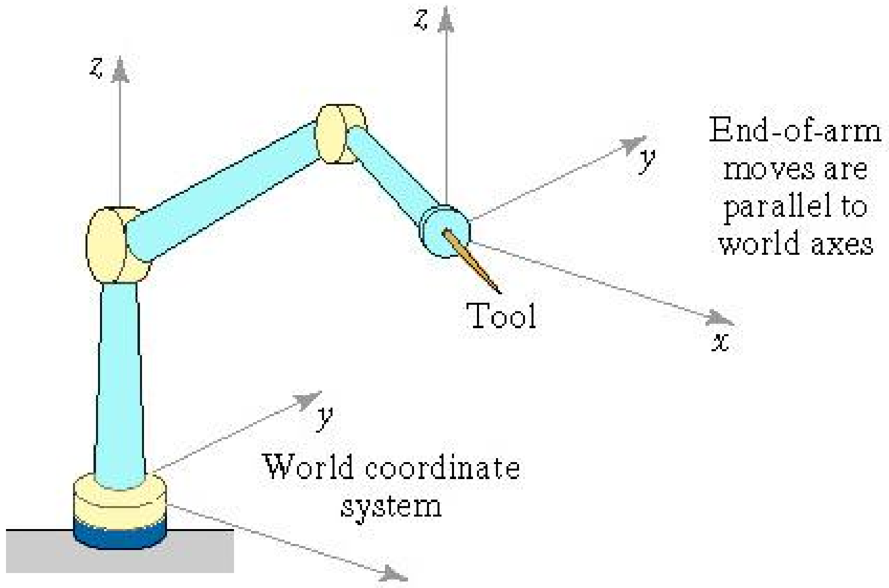
- Advantages:
  - Easily learned by shop personnel
  - Logical way to teach a robot
  - No computer programming
- Disadvantages:
  - Downtime during programming
  - Limited programming logic capability
  - Not compatible with supervisory control

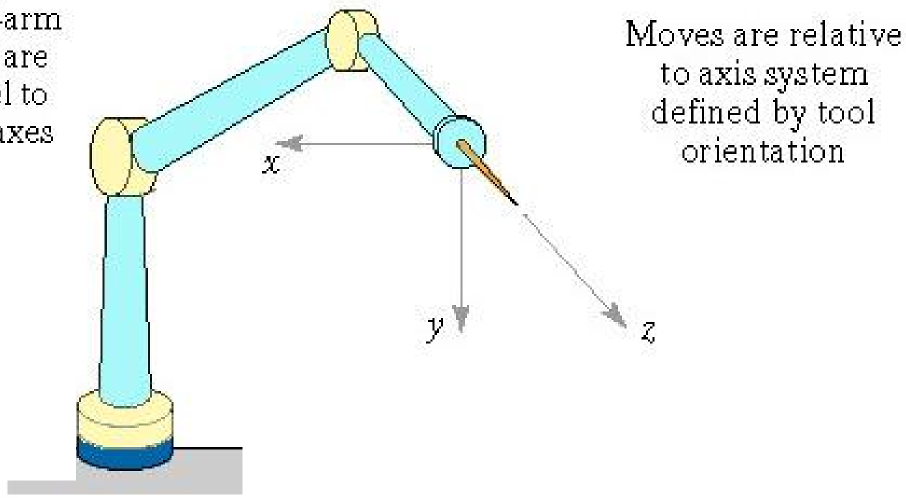
Robot Programming

- Textural programming languages
- Enhanced sensor capabilities
- Improved output capabilities to control external equipment
- Program logic
- Computations and data processing
- Communications with supervisory computers



Coordinate Systems





World coordinate system

Tool coordinate system

Motion Commands

MOVE P1

HERE P1 - used during lead through of manipulator

MOVES P1

DMOVE(4, 125)

APPROACH P1, 40 MM

DEPART 40 MM

DEFINE PATH123 = PATH(P1, P2, P3)

MOVE PATH123

SPEED 75

Interlock and Sensor Commands

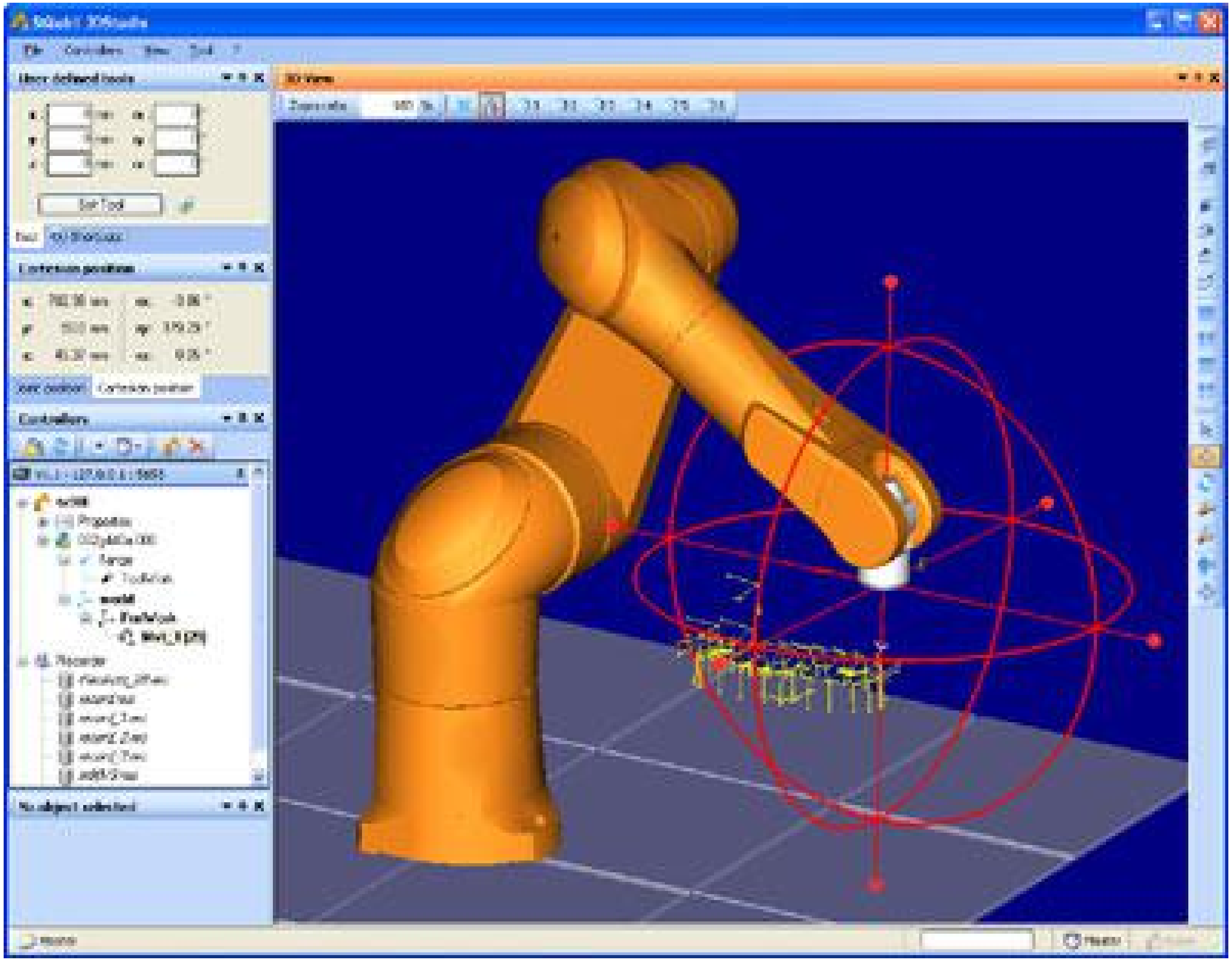
Interlock Commands

- WAIT 20, ON
- SIGNAL 10, ON
- SIGNAL 10, 6.0
- REACT 25, SAFESTOP

Gripper Commands

- OPEN
- CLOSE
- CLOSE 25 MM
- CLOSE 2.0 N

Simulation and Off-Line Programming



Example

A robot performs a loading and unloading operation for a machine tool as follows:

- Robot pick up part from conveyor and loads into machine (Time=5.5 sec)
- Machining cycle (automatic). (Time=33.0 sec)
- Robot retrieves part from machine and deposits to outgoing conveyor. (Time=4.8 sec)
- Robot moves back to pickup position. (Time=1.7 sec)

Every 30 work parts, the cutting tools in the machine are changed which takes 3.0 minutes. The uptime efficiency of the robot is 97%; and the uptime efficiency of the machine tool is 98% which rarely overlap.

Determine the hourly production rate.

Solution

$T_c = 5.5 + 33.0 + 4.8 + 1.7 = 45$ sec/cycle

Tool change time $T_{tc} = 180$ sec/30 pc = 6 sec/pc

Robot uptime $E_R = 0.97$, lost time = 0.03.

Machine tool uptime $E_M = 0.98$, lost time = 0.02.

Total time = $T_c + T_{tc}/30 = 45 + 6 = 51$ sec = 0.85 min/pc

$R_c = 60/0.85 = 70.59$ pc/hr

Accounting for uptime efficiencies,

$R_p = 70.59(1.0 - 0.03 - 0.02) = 67.06$ pc/hr

Computer Integrated Manufacturing (CIM)

- Computer Aided Design (CAD)
  - 2D
  - 3D
  - Concurrent Engineering
- Computer Aided Process Planning (CAPP)
  - Variant
  - Generative
- Computer Aided Manufacturing (CAM)
  - CNC
  - Robotics
  - Material Handling
  - Just in Time (JIT)
  - Group Technology
  - Flexible Manufacturing Systems

What is process planning?

- Recipe/Algorithm/Step-by-step instructions
- Fast Food Chain
- Same taste everywhere from NY to LA
- How do they do it?
- Customization in formal dinner restaurant

Manufacturing Environment

- Role of the master machinist in small batch manufacturing
- Manufacturing is more complex than cooking yet the planning for it is similar
- Job shop: group machines which perform same operation together
- Routing of parts through the various departments
- Process plan defines the route
- Reduction in the necessary skill of operator can be achieved by using a detailed process plan

Formal Definition

"Process planning can be defined as an act of preparing processing documentation for the manufacturing of a piece, part or an assembly"

- depending on the production environment can be
  - Rough
  - Detailed
- When process planning is done using a computer : "Computer Aided Process Planning"

Step-by-step operations in a sample part

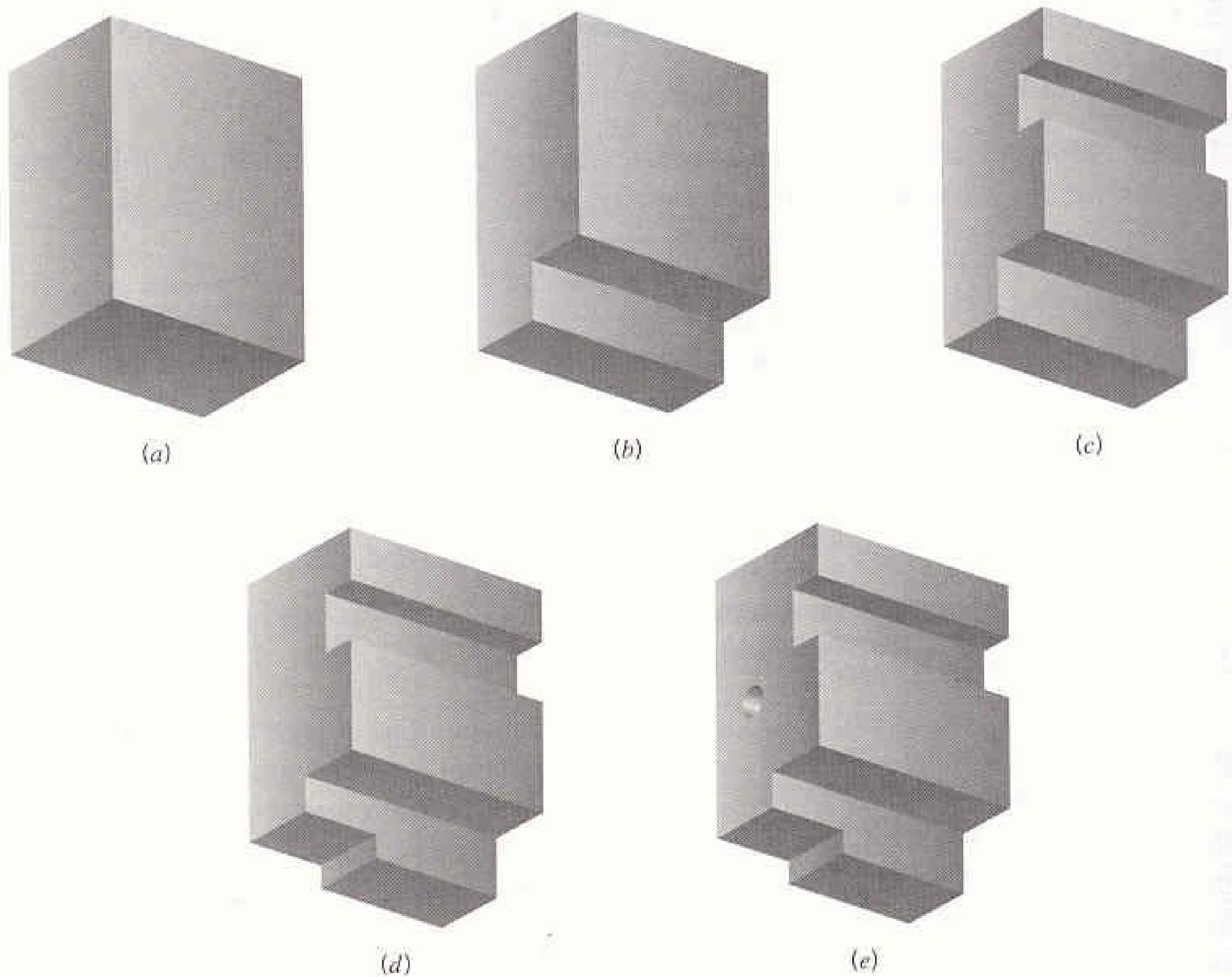


FIGURE 5.7 Successive modification of a part: (*a*) part with plane geometric features; (*b*) step addition; (*c*) slot addition; (*d*) side step addition; (*e*) a blind cylindrical hole addition.

Manufacturing a part to meet design specs.

- Selection of initial block
- Sequence of operations
- Selection of machine, process
  - Surface finish
  - Quality
  - Tolerance
  - Hardness
  - Life
  - Cost

A Rough Process Plan

Route Sheet — by: T.C. Chang

Part No. S1243
Part Name: Mounting Bracket

workstation	Time(min)
1. Mtl Rm	
2. Mill02	5
3. Drl01	4
4. Insp	1

Figure 1.1 A rough process plan

A Detailed Process Plan

PROCESS PLAN — ACE Inc.

Part No. S0125-F
Part Name: Housing
Original: S.D. Smart Date: 1/1/89
Checked: C.S. Good Date: 2/1/89

Material: steel 4340Si

Changes: ______ Date: ______
Approved: T.C. Chang Date: 2/14/89

No.	Operation Description	Workstation	Setup	Tool	Time (Min)
10	Mill bottom surface1	MILL01	see attach#1 for illustration	Face mill 6 teeth/4" dia	3 setup 5 machining
20	Mill top surface	MILL01	see attach#1	Face mill 6 teeth/4" dia	2 setup 6 machining
30	Drill 4 holes	DRL02	set on surface1	twist drill 1/2" dia 2" long	2 setup 3 machining

Components of Process Planning

- Selection of machining operations
- Sequencing of machining operations
- Selection of cutting tools
- Determining the setup requirements
- Calculation of cutting parameters
- Tool path planning and generation of NC/CNC programs
- Design of Jigs/Fixtures

Process Planning in different environments

- In tool-room type manufacturing
  - “make part as per drawing” is sufficient
- In metal-forming type operations
  - The process planning requirements are embedded directly into the die.
  - Process planning is fairly trivial
- Job-shop type manufacturing requires most detailed process planning
  - Design of tools, jigs, fixtures and manufacturing sequence are dictated directly by the process plan.

Requirements for process planner

- Must be able to analyze and understand part requirements
- Have extensive knowledge of machine tools, cutting tools and their capabilities
- Understand the interactions between the part, manufacturing, quality and cost

Traditional process planning

- Experienced based and performed manually
- Variability in planner's judgment and experience can lead to differences in the of what constitutes best quality
- Problem facing modern industry is the current lack of skilled labor force to produce machined parts as was done in the past
- Hence Computer Integrated Manufacturing and Computer Aided Process Planning

Advantages of CAPP

- Reduces the demand on the skilled planner
- Reduces the process planning time
- Reduces both process planning and manufacturing cost
- Creates consistent plans
- It produces accurate plans
- It increases productivity

Approaches to CAPP

- Variant
- Generative
- Automatic

Variant Process Planning

"Based on the valid conjecture that similar parts will have similar process plans"

Preparatory stage

- GT-based part coding
  - Families of similar parts are created
  - Family matrix
- A process plan is to manufacture the entire family is created

Variant Process Planning

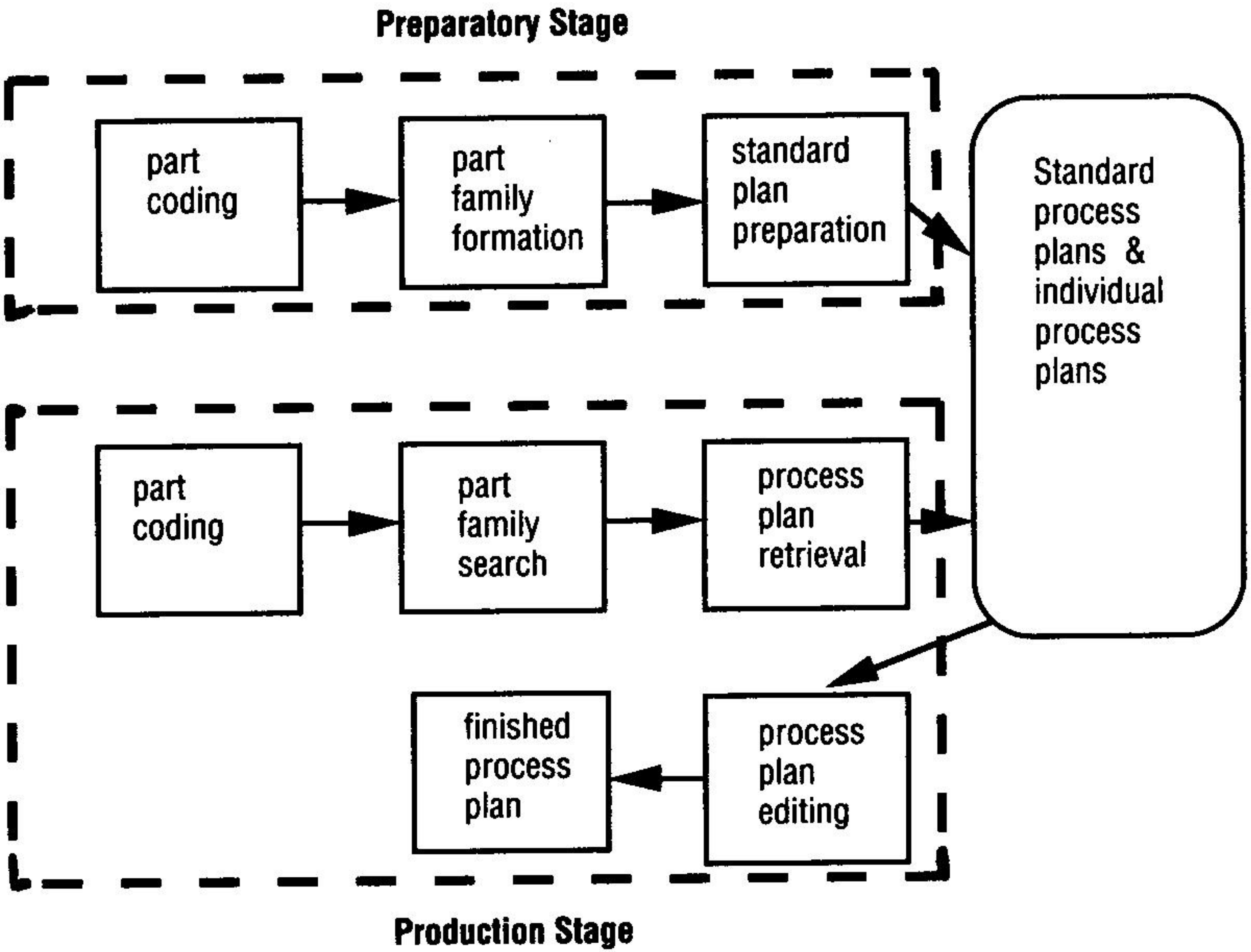
Production Stage

- Incoming part is coded
- Part family is identified
- Process plan is edited to account for the different needs of the part

Salient points of variant process planning

- Easy to build, learn and use
- Experienced process planners are still required to edit the process plan
- Cannot be used in an entirely automated manufacturing system without additional process planning

Variant Process Planning



Generative Process Planning

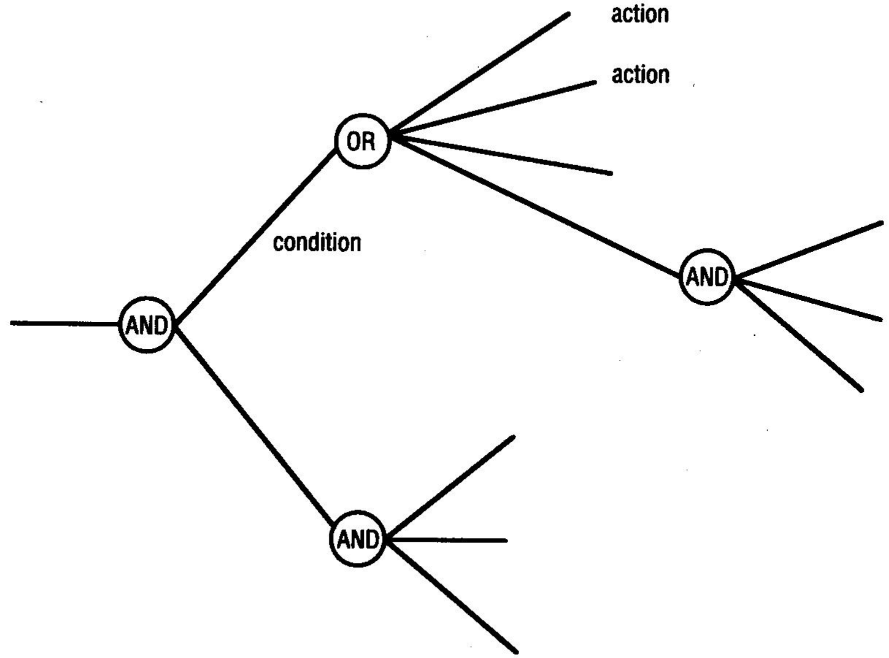
"A system which automatically synthesizes a process plan for a new component"

Requires

- Part description
  - Part to be produced must be clearly and precisely defined in a computer compatible format (OPITZ,AUTAP)
- Manufacturing databases
  - Logic of manufacturing must be identified and captured
  - The captured logic must be incorporated in a unified manufacturing database

Generative Process Planning

- Decision making logic and algorithms
  - Decision trees
  - Expert Systems:
  - AI based approaches



Automatic Process Planning

" Generate a complete process plan directly from a CAD drawing"

Requires:

- Automated CAD interface
  - Take a general CAD model (3D for unambiguous data) and develop an interface to develop a manufacturing interface for this model : Feature Recognition of CAD
  - Design the parts with available manufacturing features : Feature based CAD
  - Dual: useful features of both approaches
- Intelligent (computer based) process planner

Some process planning approaches

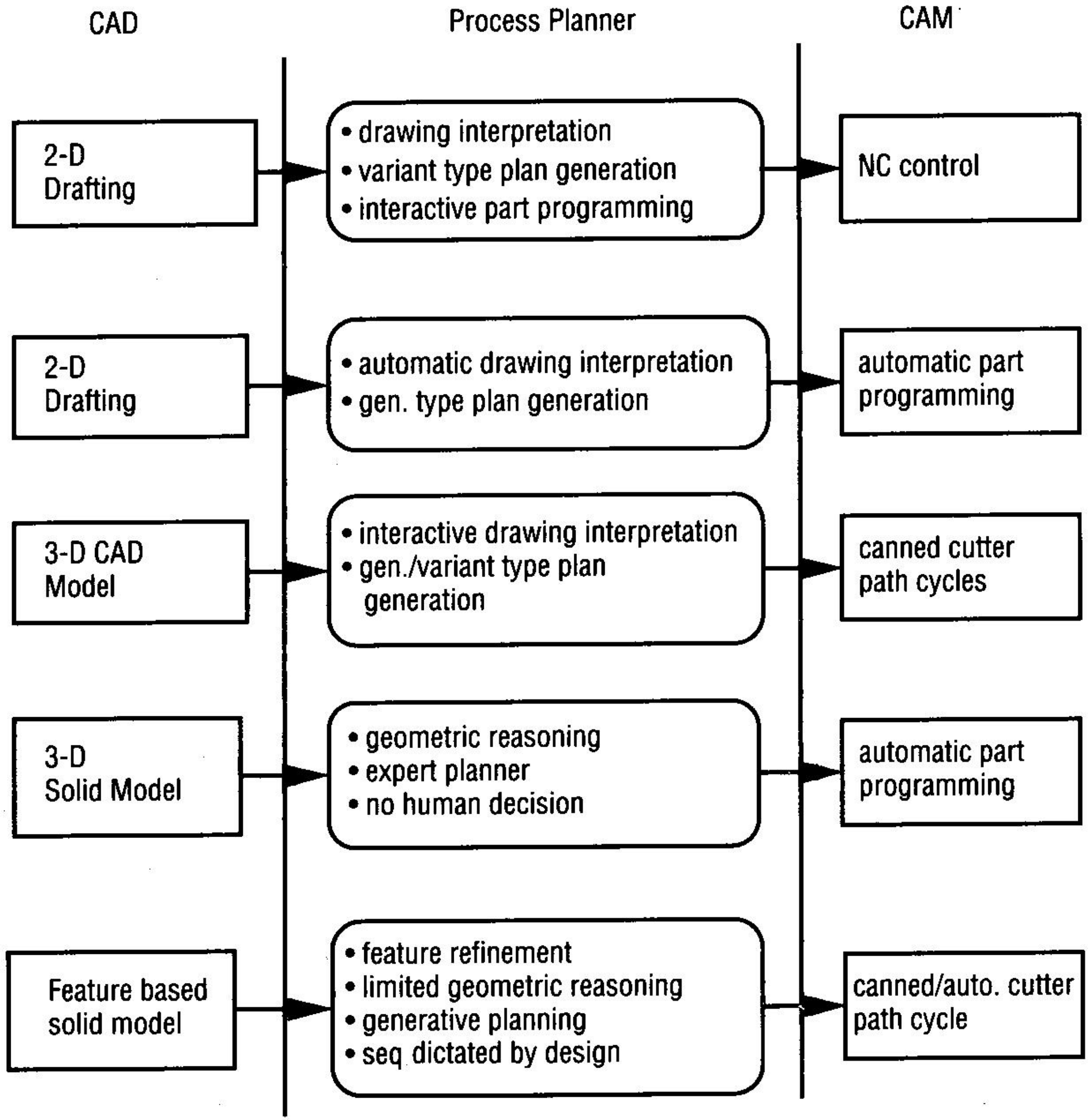


Figure 1.14 Some process planning approaches