- Computerized
- Numeric
- Control
Benefits

■ Automation
■ Precision
■ Repeatability
■ Flexibility
Examples

- Cutters
- Mills
- 3D Printers
- Lathes
- Knitting

stoll cnc knitting machine
CNC History

John T Parsons + MIT 1949
Categories

- Additive
- Subtractive

additive

subtractive
Axes

- How Many?
  - 1D
  - 2D
  - 2.5D
  - 3D
  - 5D
  - linear

- What Kind?
  - rotary
  - linear
- how big
- shape
- constraints

by xiyang yeh @ stanford
- how fast to do cut
- up to speed of breaking end mill
- more but slower cuts
open loop
- crash

closed loop
- limit switch
- rotary encoder
- camera
- width of saw blade
- cut radius
- must compensate in code
extra cut to compensate for mill radius
- extra cut during start or finish of cut
- usually need to plan for this

by big blue saw
- Rectangular
- Precision – increments
- Origin – Zeroing
- Absolute and Relative

![Coordinate System Image]
Tool Changing

- different cutters
- thicker mill cuts faster but less precise
- switch between them under program control
word addressed format for programming
sentence like commands: letter followed by numeric argument
command is made up of words often one letter with intuitive interpretations
step by step commands
read interpret execute each command

X10
Y20
<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>O</td>
<td>Program number (Used for program identification)</td>
</tr>
<tr>
<td>N</td>
<td>Sequence number (Used for line identification)</td>
</tr>
<tr>
<td>G</td>
<td>Preparatory function (See below)</td>
</tr>
<tr>
<td>X</td>
<td>X-axis designation</td>
</tr>
<tr>
<td>Y</td>
<td>Y-axis designation</td>
</tr>
<tr>
<td>Z</td>
<td>Z-axis designation</td>
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<tr>
<td>R</td>
<td>Radius designation</td>
</tr>
<tr>
<td>F</td>
<td>Feedrate designation</td>
</tr>
<tr>
<td>S</td>
<td>Spindle speed designation</td>
</tr>
<tr>
<td>H</td>
<td>Tool length offset designation</td>
</tr>
<tr>
<td>D</td>
<td>Tool radius offset designation</td>
</tr>
<tr>
<td>T</td>
<td>Tool Designation</td>
</tr>
<tr>
<td>M</td>
<td>Miscellaneous function</td>
</tr>
</tbody>
</table>
Example GCode Program

G1 X5 Y-5 Z6 F3300.0 (Move to position <x,y,z>=<5,-5,6> at speed 3300.0)
G21 (set units to mm)
G90 (set positioning to absolute)
G92 X0 Y0 Z0 (set current position to <x,y,z>=<0,0,0>)
Manufacturer Specific Commands

- G90, G91
- Spindle speed
- Coolant
- Tool changing
Programming

- like turtle graphics
  - move
  - pen up/down
- no loops
- no subroutines
- send gcode to CNC machine
- machine interprets one command at a time
- usually microcontroller which is interpreting and executing

tinyg microcontroller board
organize cuts efficiently
plan motions according to dynamics
change speeds
bang-bang control
- need to plan cuts so parts are cut correctly
- cut holes out first
- much more involved for 5 axis machines
Traveling Salesman Problem

- salesman has to visit n cities in minimum time

GLPK solution by xypron
- show planned out motions
- actually interpret gcode
- validate that plan works

by modern machine shop
- show feedback during execution
- communicate to user for manual intervention
- WYSIWYG
Input Formats

- DXF, SVG, PDF – polylines
- STL, OBJ – meshes
- AMF – materials, frep

```
solid name
facet normal ni nj nk
   outer loop
      vertex v1x v1y v1z
      vertex v2x v2y v2z
      vertex v3x v3y v3z
   endloop
endfacet
endsolid name
```
AMF – http://www.astm.org/Standards/ISOASTM52915.htm