Computational Design + Fabrication: 4D Analysis

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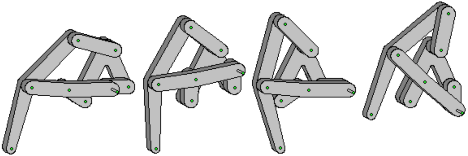
October 6, 2015

- News
- Torque and Work
- Simple Machines
- Closed Chains
- Analysis
- Paper Review
- Lab 3 Critique

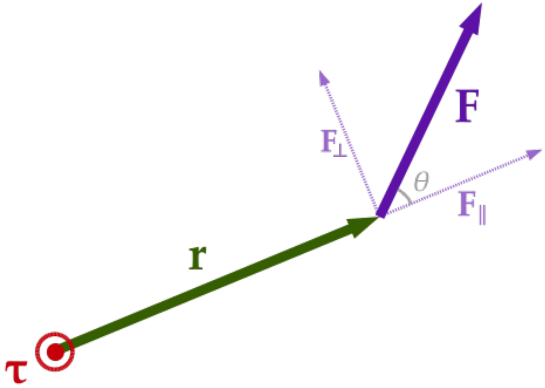


News

- reading 5 out – read pages 1-3
- lab 4 out after class
- section now on mondays 1-2p in jacobs 210

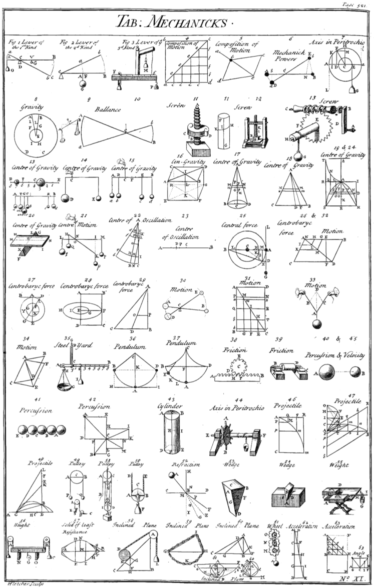
Torque

- rotational force
- force at radius
- torque is cross product of force and radius vectors



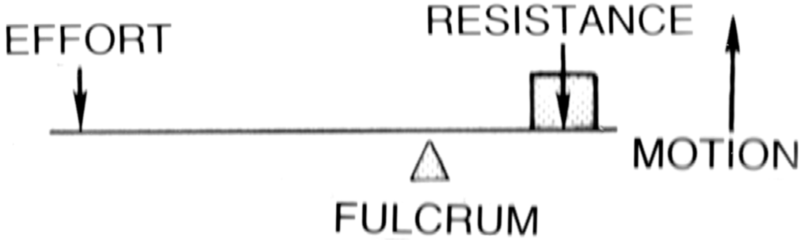
by StradivariusTV

- mechanical device to change direction or magnitude of force
- usually use mechanical advantage to amplify force



Lever

- simple 2 bar linkage
- effort
- fulcrum
- resistance

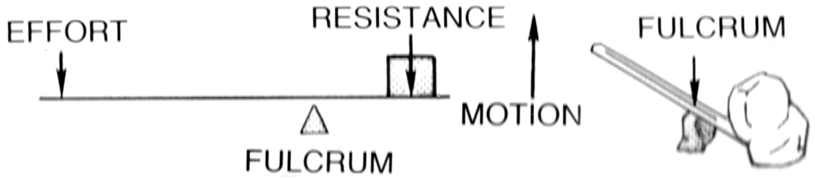


by Pearson Scott Foresman

- **Work** = Force * Distance
- **Work Conservation** = Work on both ends of lever must equal
- **Mechanical Advantage** = ratio of output to input forces equal ratio of distances

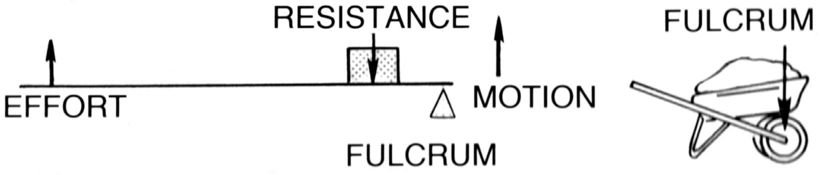
Class 1

- fulcrum in middle
- see-saw, crow bar, or scissors
- mechanical advantage can be greater than one



by Pearson Scott Foresman

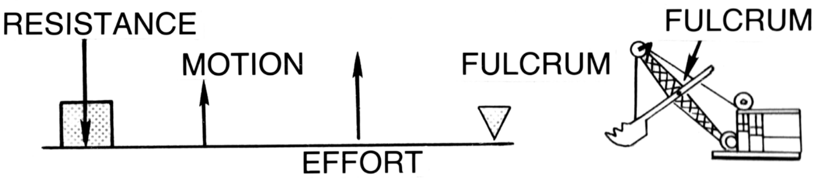
- resistence in middle
- wheel barrow, nutcracker, bottle opener, or brake pedal
- mechanical advantage is always greater than one



by Pearson Scott Foresman

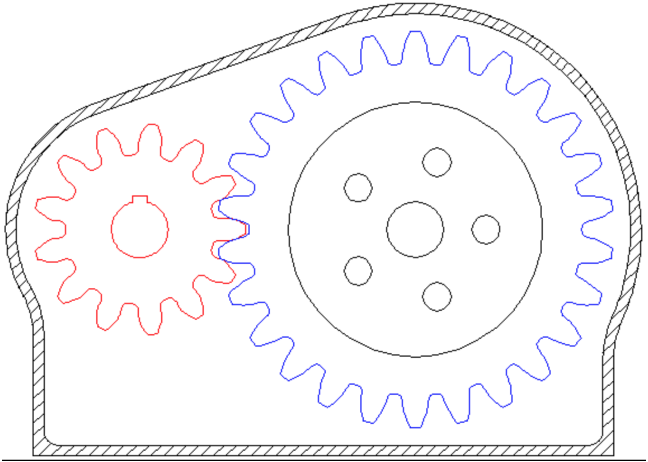
Class 3

- effort in middle
- crane, tweezers, or mandible
- mechanical advantage is always less than one

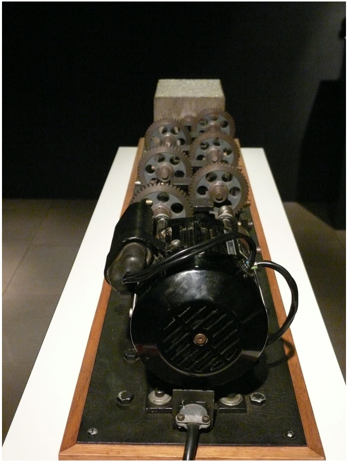


by Pearson Scott Foresman

- driver / follower
- mechanical advantage
- gear ratio



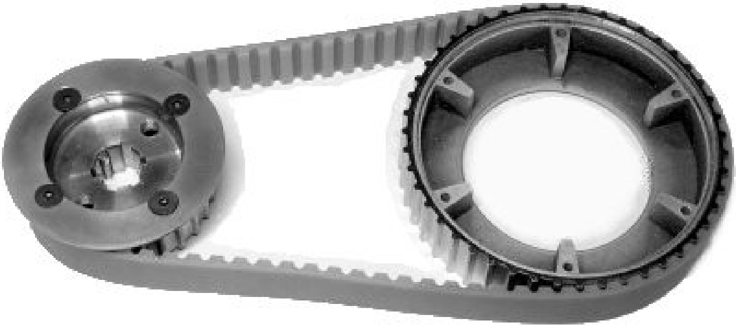
- gears in series
- successive change in mechanical advantage



by Arthur Ganson photo by Shervinafshar

Belt Drives

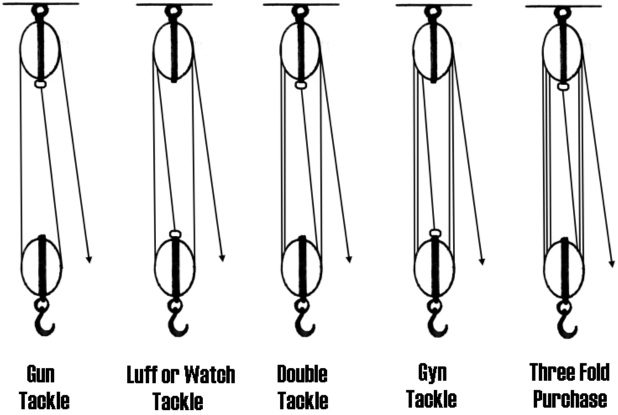
- teeth
- chain



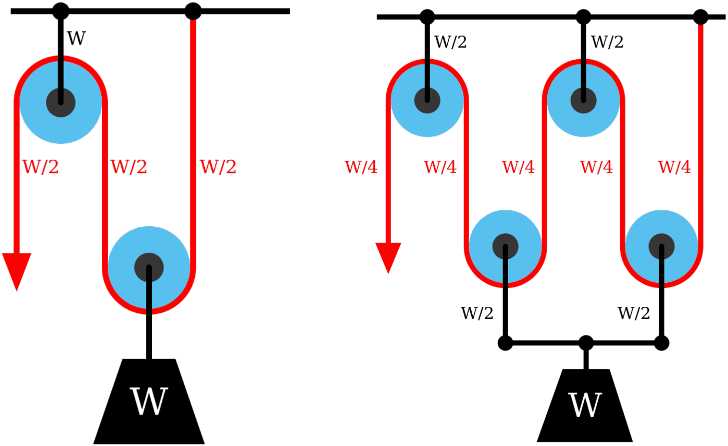
source Norman Hyde

Pulley

- changes direction of force
- split force between sides of pulley
- reduce force using multiple pulley stages



by Welkinridge



W
W/2
W/2
W/2
W
W/2
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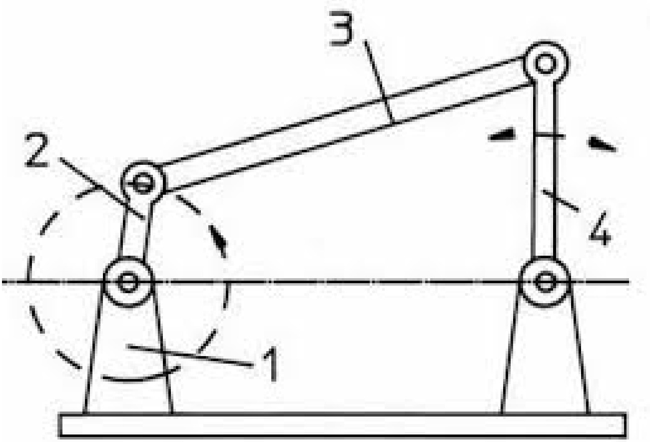
W

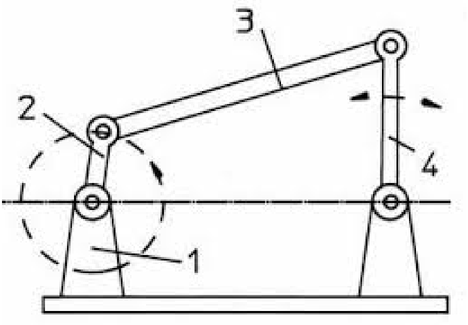
- loop in linkage
- less degrees of freedom than number of joints
- loop constraint



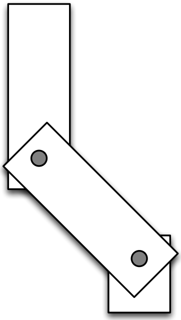
by Ruiz + Wirth

DOF Equation

- F = 3(n - 1) - 2f where n = num links and f = num nodes
- F = 3(4 - 1) - 2*4 = 9 - 8 = 1 for four bar RRRR
- F = 3(3 - 1) - 2*2 = 6 - 4 = 2 for two bar RR



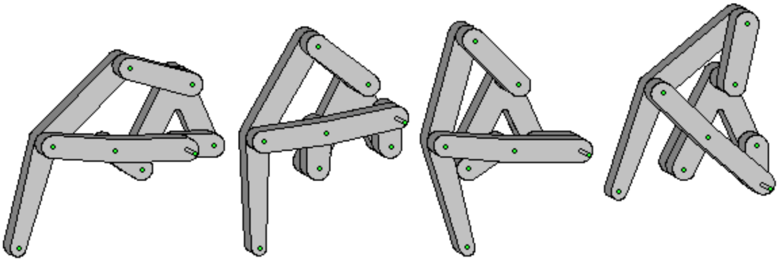
RRRR by Ruiz + Wirth



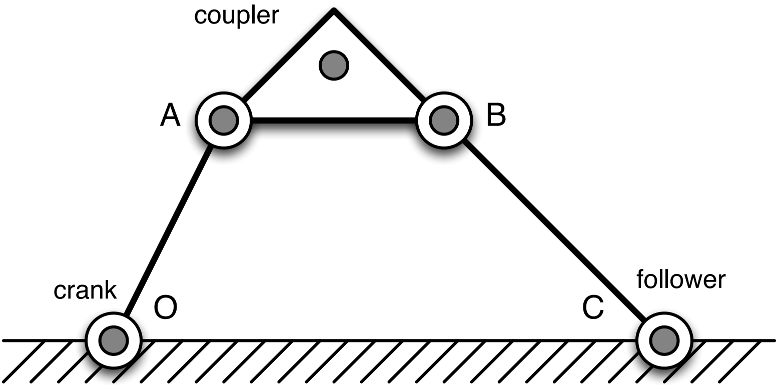
RR

Why Closed Chains?

- simplicity
- efficiency
- strength

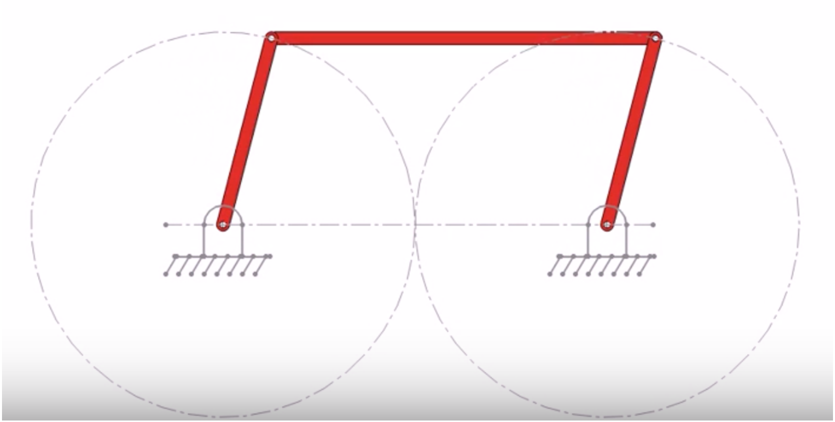


- crank / driver
- coupler
- follower



- coupler parallel to ground

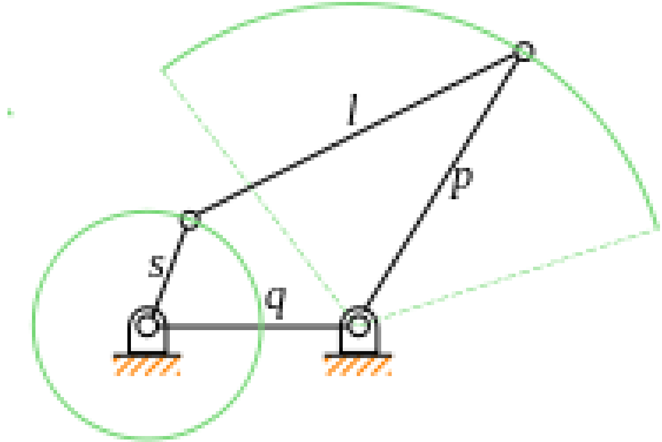
(1)



by ibrahim saed

- turn rotary into linear motion

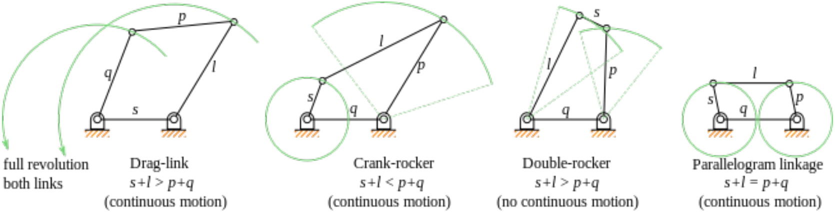
- turn rotary into rocker motion



by Salix Alba

- S = shortest, L = longest, P,Q = remaining links
- $L + S < P + Q$ - shortest can rotate fully

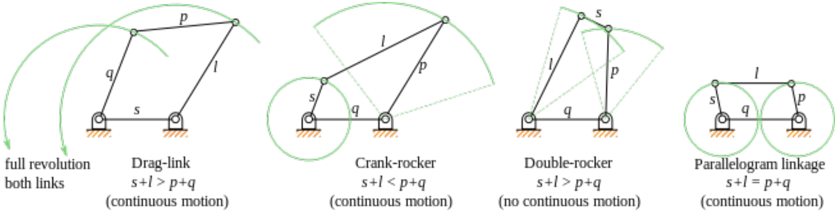
- Crank / Crank
- Crank / Rocker
- Rocker / Crank
- Rocker / Rocker



by Salix Alba

- $T1 = g + h - a - b$
- $T2 = b + g - a - h$
- $T3 = b + h - a - g$

T1	T2	T3	Grashof	Input	Output
-	-	+	yes	crank	crank
+	+	+	yes	crank	rocker
+	-	-	yes	rocker	crank
-	+	-	yes	rocker	rocker
-	-	-	no	0-rocker	0-rocker
-	+	+	no	π-rocker	π-rocker
+	-	+	no	π-rocker	0-rocker
+	+	-	no	0-rocker	π-rocker

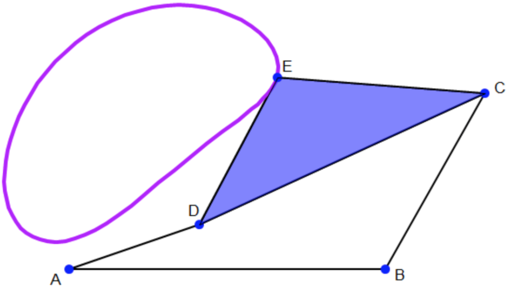


by Salix Alba

$$Q = \frac{TimeofSlowerStroke}{TImeofFasterStroke} \geq 1 \qquad (2)$$

- four bar has two strokes, the forward and the return
- cycle = forward + return strokes
- symmetric
  - windshield wiper
  - window crank
- asymmetric – work done in one direction – return fast = offset
  - cutting machines
  - package-moving devices

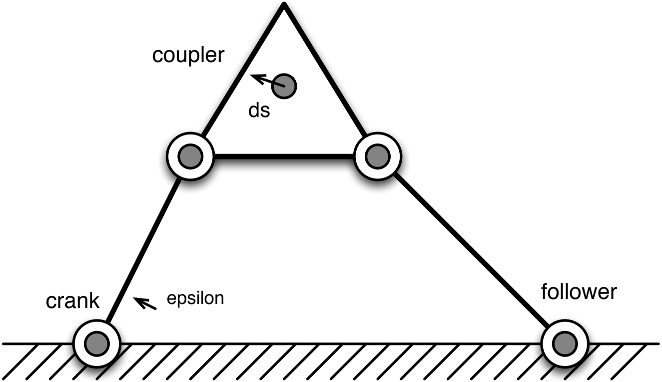
- graphically display mechanism speed of trajectory
- estimate velocities and accelerations



https://en.wikipedia.org/wiki/Four-bar_linkage#/media/File:4_bar_linkage_animated.gif

Mechanical Advantage at Instant

- Perturb the input crank by some small ϵ
- Find the distance *ds* the point in question travels when the crank moves by ϵ.
- The mechanical advantage = ds/ϵ.
- torque = $F \times ds/\epsilon$ for torque required to produce a force F



- estimate mechanical advantage at a point using epsilon technique
- plot advantage over time

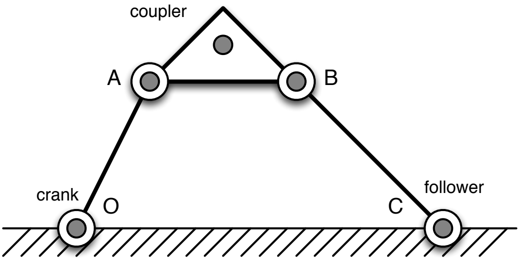
- symbolic – solve for analytic solution
- numeric – optimize to closed chain

$$\Psi(\theta) = arctan(\frac{B}{A}) \pm arccos(\frac{C}{sqrt(A^2 + B^2)}) \quad (3)$$

where

$$A^2 + B^2 - C^2 \geq 0 \quad (4)$$

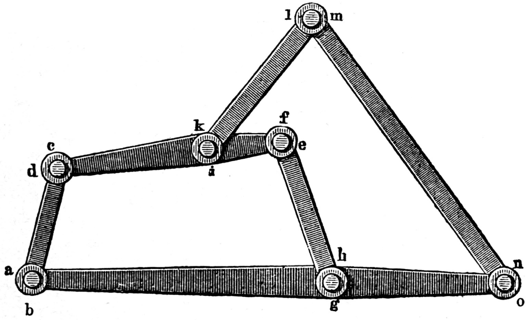
- $\pm$ for two solutions
- constraint because of $\pm$ 1 domain on arccos
- can solve for where zero



Four Bar Design Space

- folding – all joints can lie on same line
- inflection points
- limited range

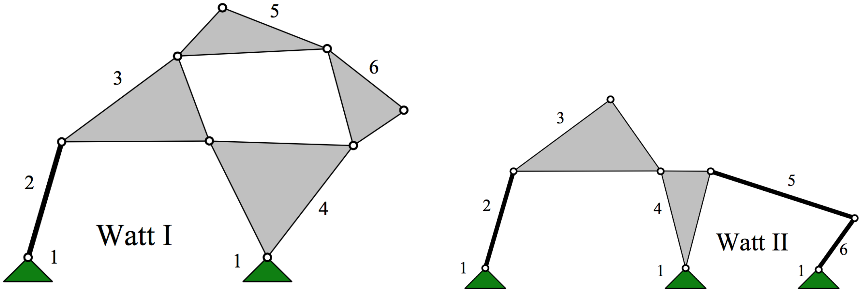
- compound linkages
- higher order polynomial
- better mechanical advantage
- harder to analyze and synthesize
- determine number of link parameters



by Franz Reuleaux

Watt Six Bar

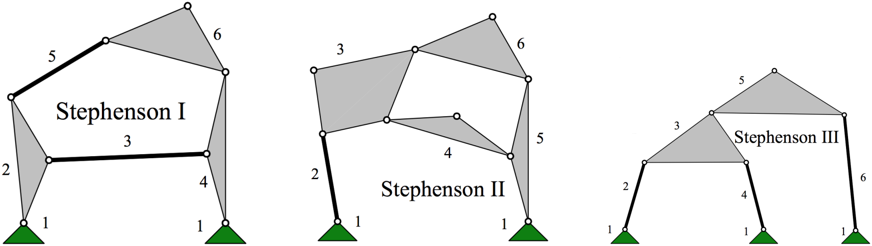
- two four bar linkages
- 12 and 11 link parameters



by Alexander Slocum

Stephenson Six Bar

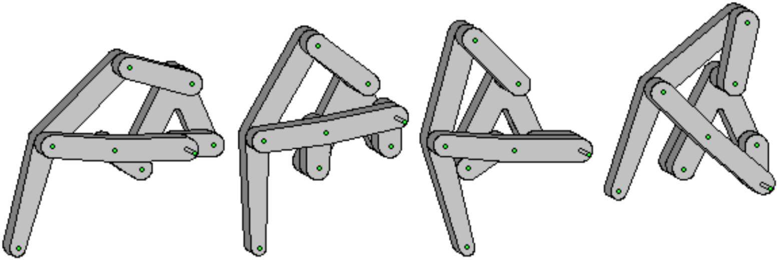
- one four and one five bar linkage
- 11,14, and 10 link parameters



by Alexander Slocum

Klann Linkage

- six bar
- linear walking motion
- quick return

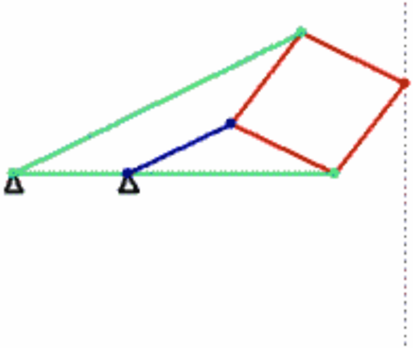


https://en.wikipedia.org/wiki/Klann_linkage#/media/File:F4-motion.gif

Universality of Revolute

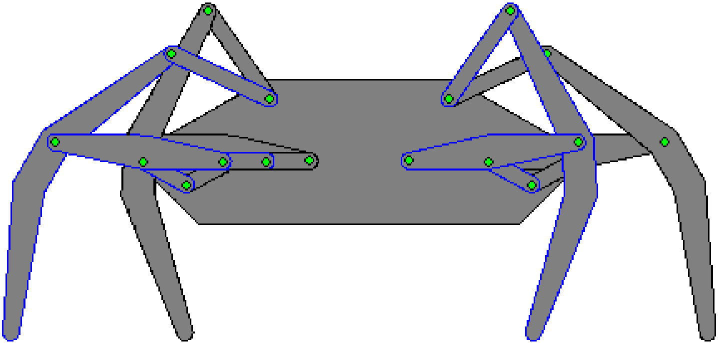
- can transform rotational to prismatic
- one planar one 3d mechanism

sarrus



peaucellier-lipkin

- place in space
- cranking out of phase



- mechanisms are mechanical computers
- solve for solution – next week
- search for solution – week after next
- program solution – stretch

- 4D Linkage Synthesis
- 4D Synthesis Paper Critique

References

- *Design FUNdaMENTALS: Linkages* by Alexander Slocum
- *Geometric Design of Linkages* by McCarthy + Soh