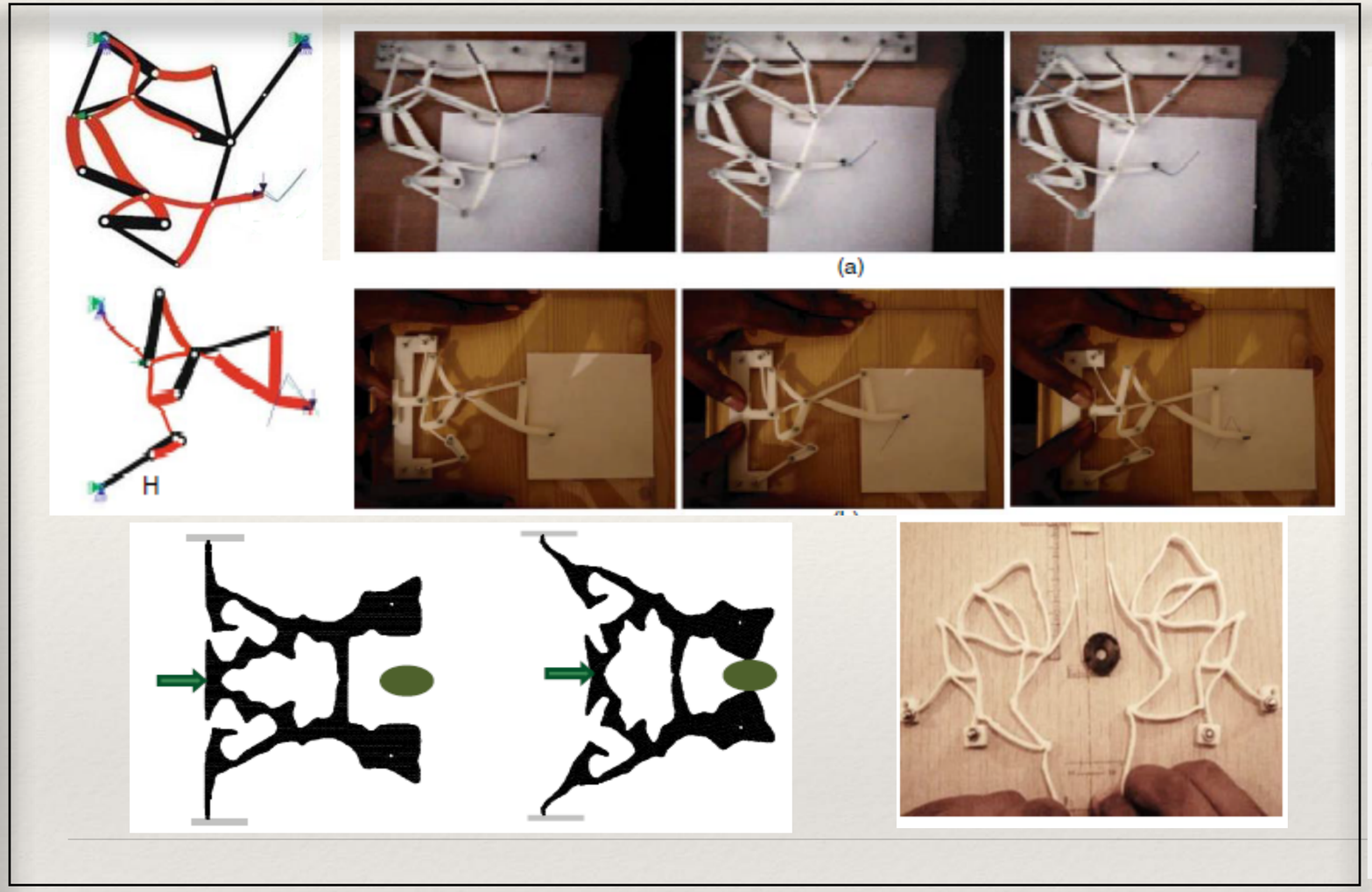
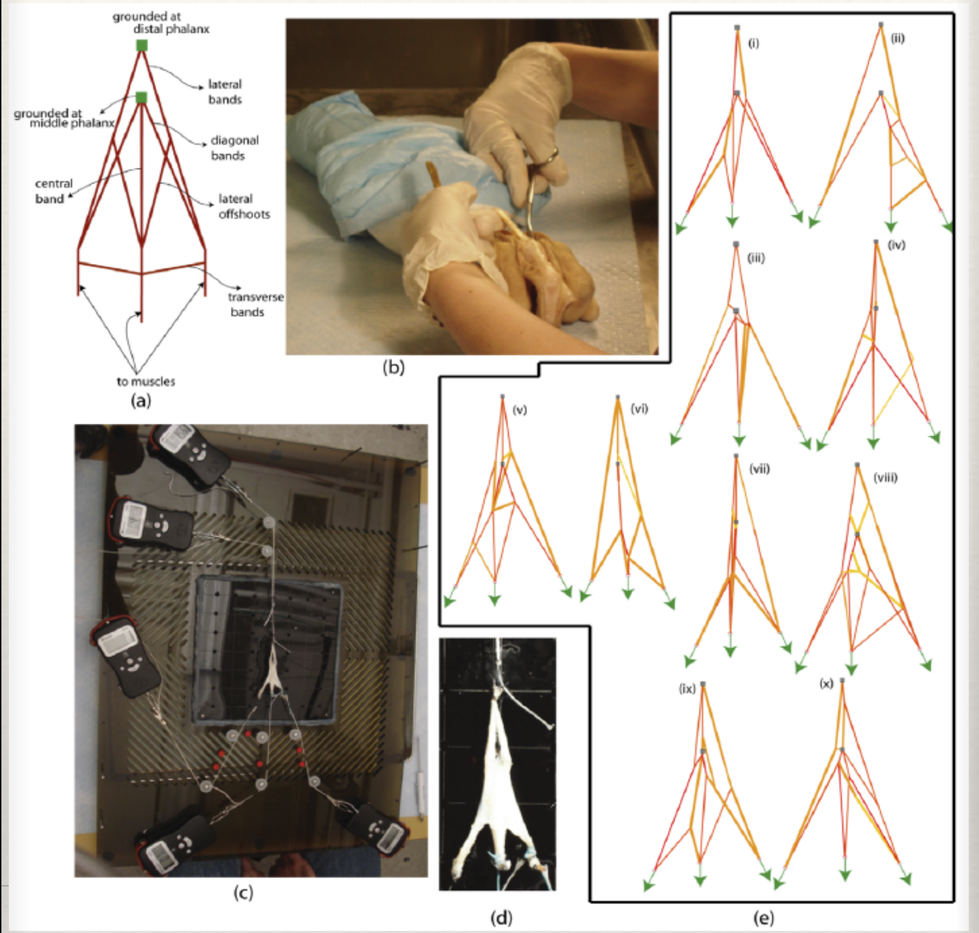
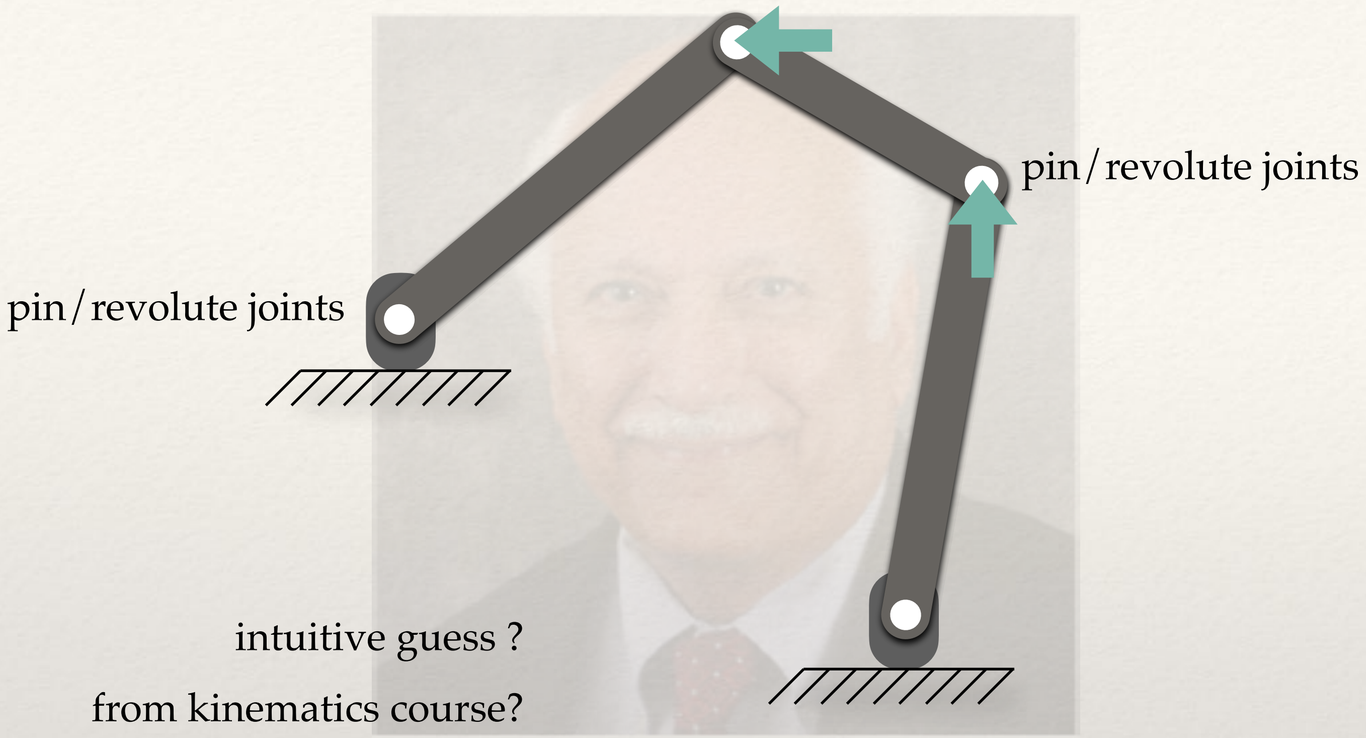




Compliant Mechanisms (ME 851)

Anupam Saxena
Professor
Indian Institute of Technology Kanpur



https://engineering.purdue.edu/ME/Seminars/2021/compliant-mechanisms-memory-lane-and-some-novel-and-exciting-applications/amidha.PNG

Prof. Ashok Midha

MECHANISMS

MANIPULATORS

they (must) move

to transmit force, motion, energy

MOBILITY ANALYSIS

is

STEP I

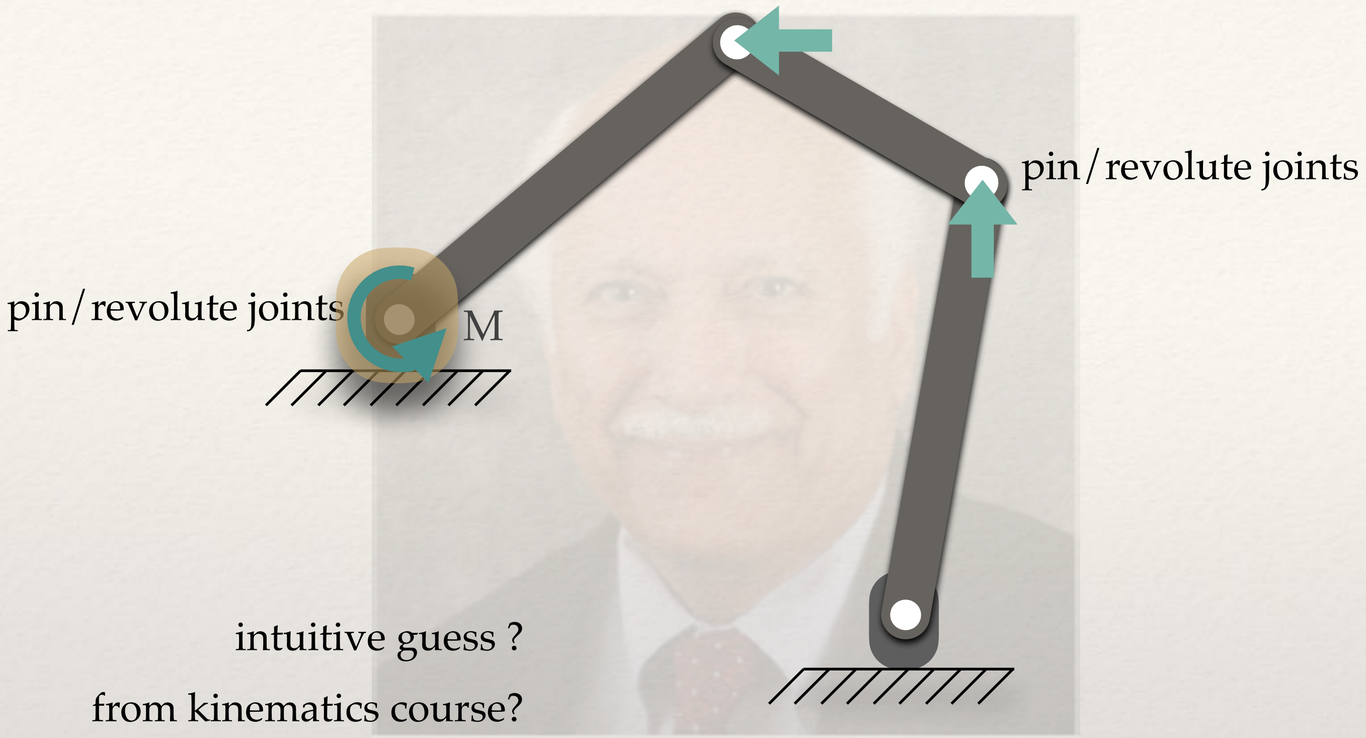
in quantification of motion

Q: How does this 4-bar linkage move?

Q: How many (minimum number of) actuations required ?

Compliant Mechanisms (ME 851)

Anupam Saxena
Professor
Indian Institute of Technology Kanpur



https://engineering.purdue.edu/ME/Seminars/2021/compliant-mechanisms-memory-lane-and-some-novel-and-exciting-applications/amidha.PNG

Prof. Ashok Midha

MECHANISMS

MANIPULATORS

they (must) move

to transmit force, motion, energy

MOBILITY ANALYSIS

is

STEP I

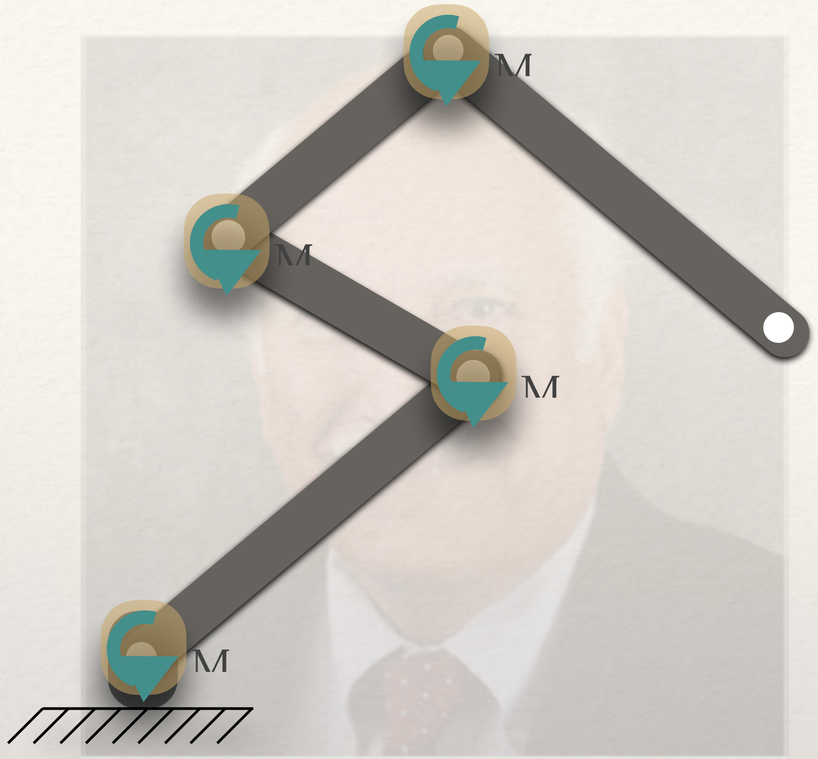
in quantification of motion

Q: How does this 4-bar linkage move?

Q: How many (minimum number of) actuations required ?

Compliant Mechanisms (ME 851)

Anupam Saxena
Professor
Indian Institute of Technology Kanpur



https://engineering.purdue.edu/ME/Seminars/2021/compliant-mechanisms-memory-lane-and-some-novel-and-exciting-applications/amidha.PNG

Prof. Ashok Midha

MECHANISMS

MANIPULATORS

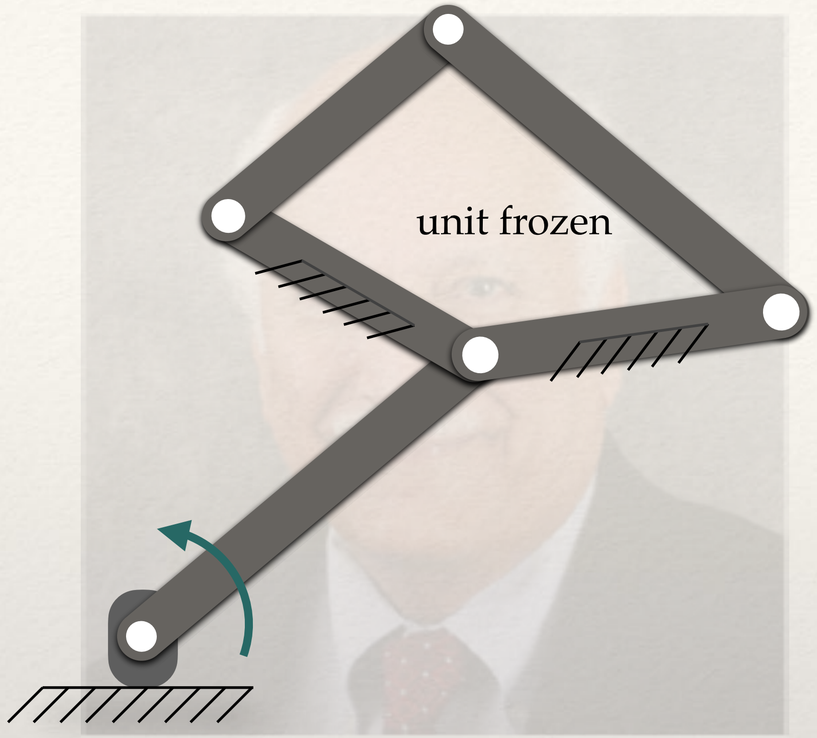
Open Chain manipulator

MOBILITY ANALYSIS

how many ways could this move?

Compliant Mechanisms (ME 851)

Anupam Saxena
Professor
Indian Institute of Technology Kanpur



https://engineering.purdue.edu/ME/Seminars/2021/compliant-mechanisms-memory-lane-and-some-novel-and-exciting-applications/amidha.PNG

Prof. Ashok Midha

MECHANISMS

MANIPULATORS

Open Chain manipulator

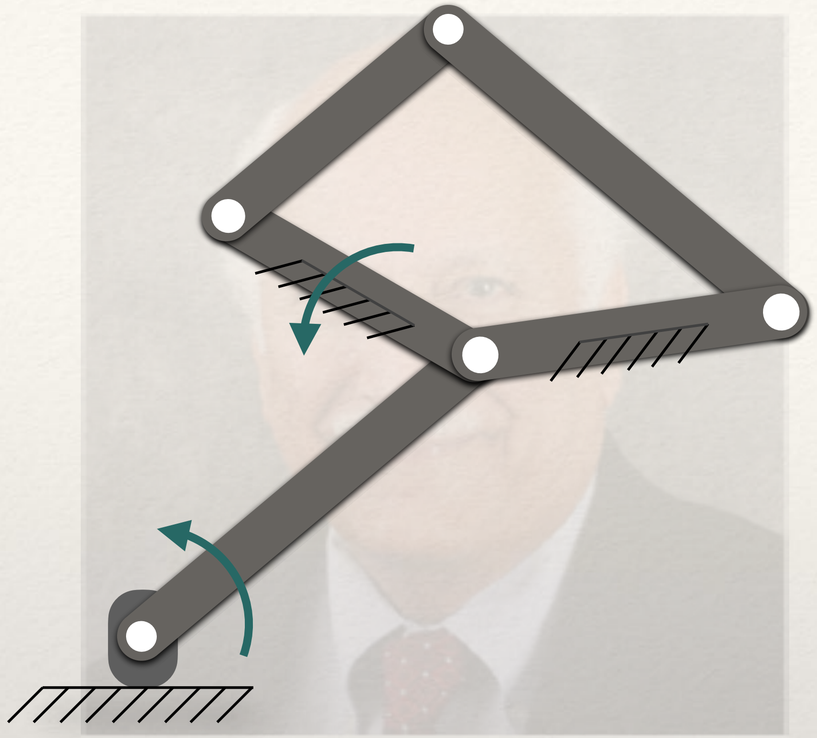
MOBILITY ANALYSIS

how many ways could this move?

how many ways, now, could this move?

Compliant Mechanisms (ME 851)

Anupam Saxena
Professor
Indian Institute of Technology Kanpur



https://engineering.purdue.edu/ME/Seminars/2021/compliant-mechanisms-memory-lane-and-some-novel-and-exciting-applications/amidha.PNG

Prof. Ashok Midha

MECHANISMS

MANIPULATORS

Open Chain manipulator

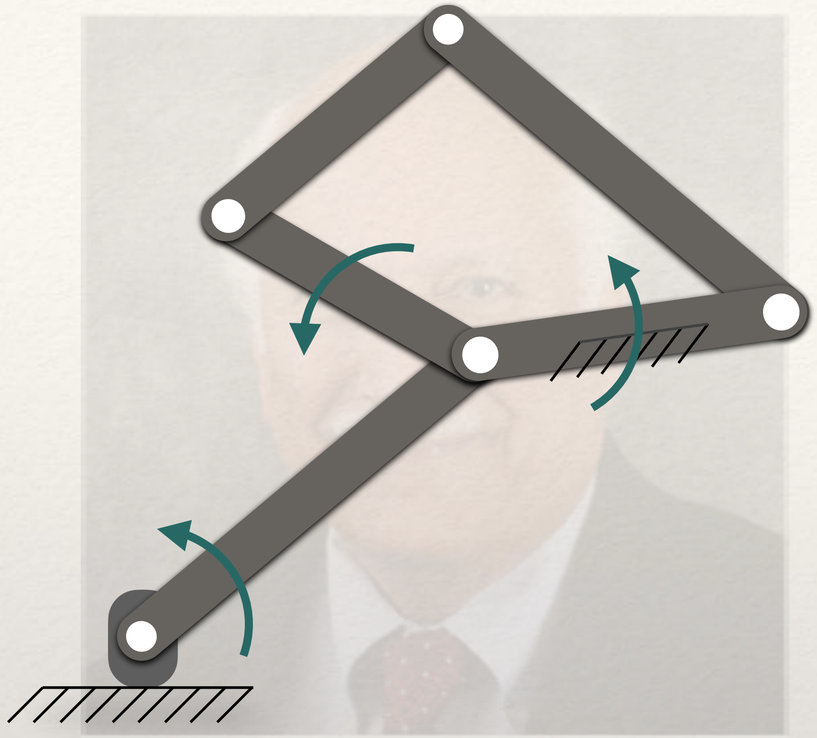
MOBILITY ANALYSIS

how many ways could this move?

how many ways, now, could this move?

Compliant Mechanisms (ME 851)

Anupam Saxena
Professor
Indian Institute of Technology Kanpur



https://engineering.purdue.edu/ME/Seminars/2021/compliant-mechanisms-memory-lane-and-some-novel-and-exciting-applications/amidha.PNG

Prof. Ashok Midha

MECHANISMS

MANIPULATORS

Open Chain manipulator

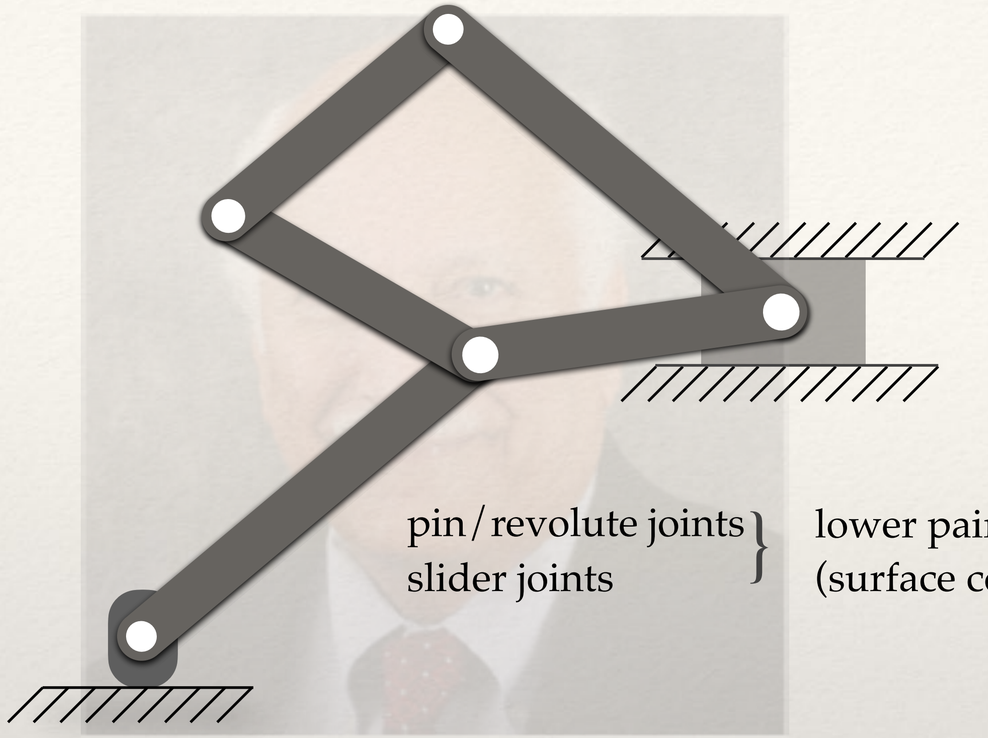
MOBILITY ANALYSIS

how many ways could this move?

how many ways, now, could this move?

Compliant Mechanisms (ME 851)

Anupam Saxena
Professor
Indian Institute of Technology Kanpur



pin/revolute joints
slider joints
} lower pairs (surface contact)

https://engineering.purdue.edu/ME/Seminars/2021/compliant-mechanisms-memory-lane-and-some-novel-and-exciting-applications/amidha.PNG

Prof. Ashok Midha

MECHANISMS

MANIPULATORS

Open Chain manipulator

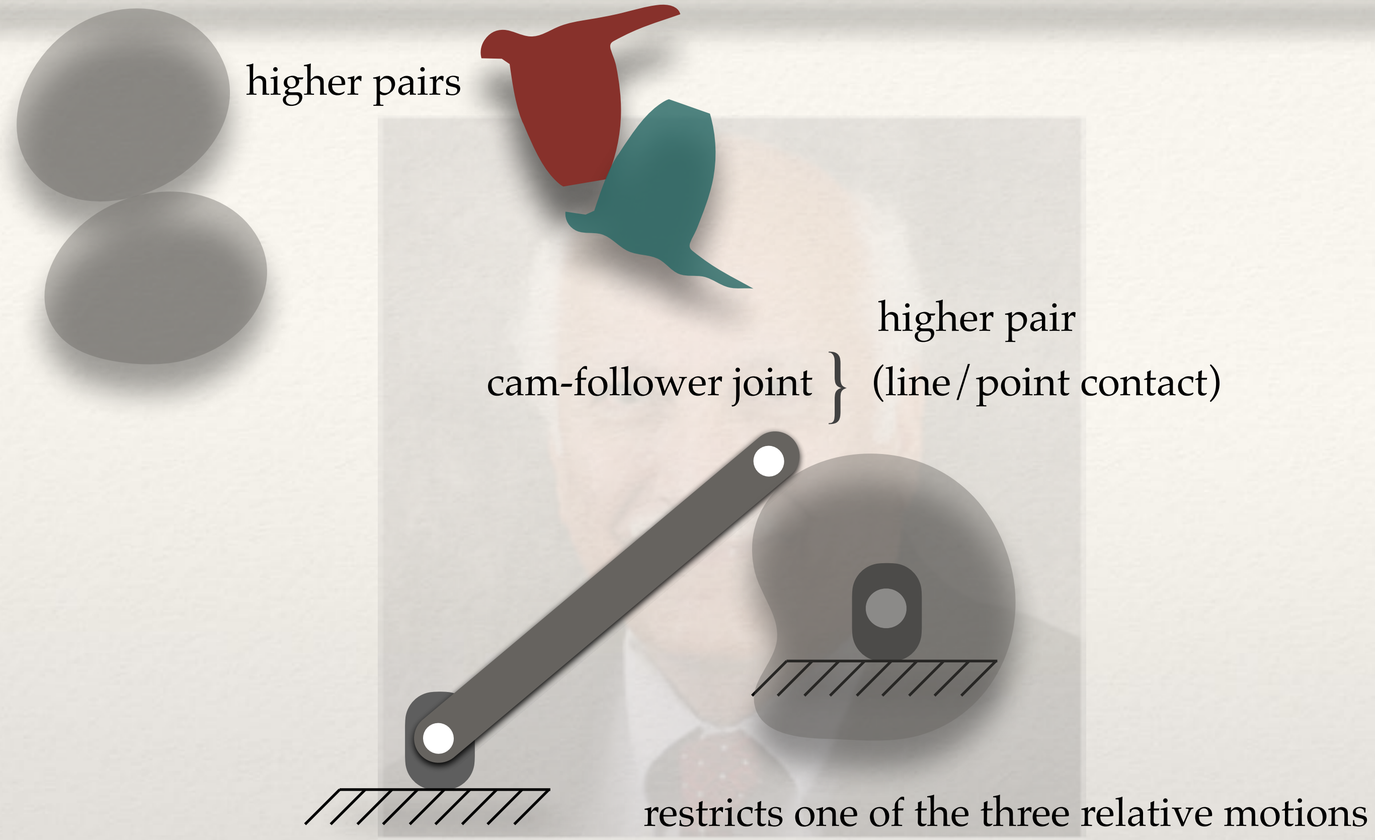
MOBILITY ANALYSIS

how many ways could this move?

how many ways, now, would this system move?

Compliant Mechanisms (ME 851)

Anupam Saxena
Professor
Indian Institute of Technology Kanpur



MECHANISMS

MANIPULATORS

Open Chain manipulator

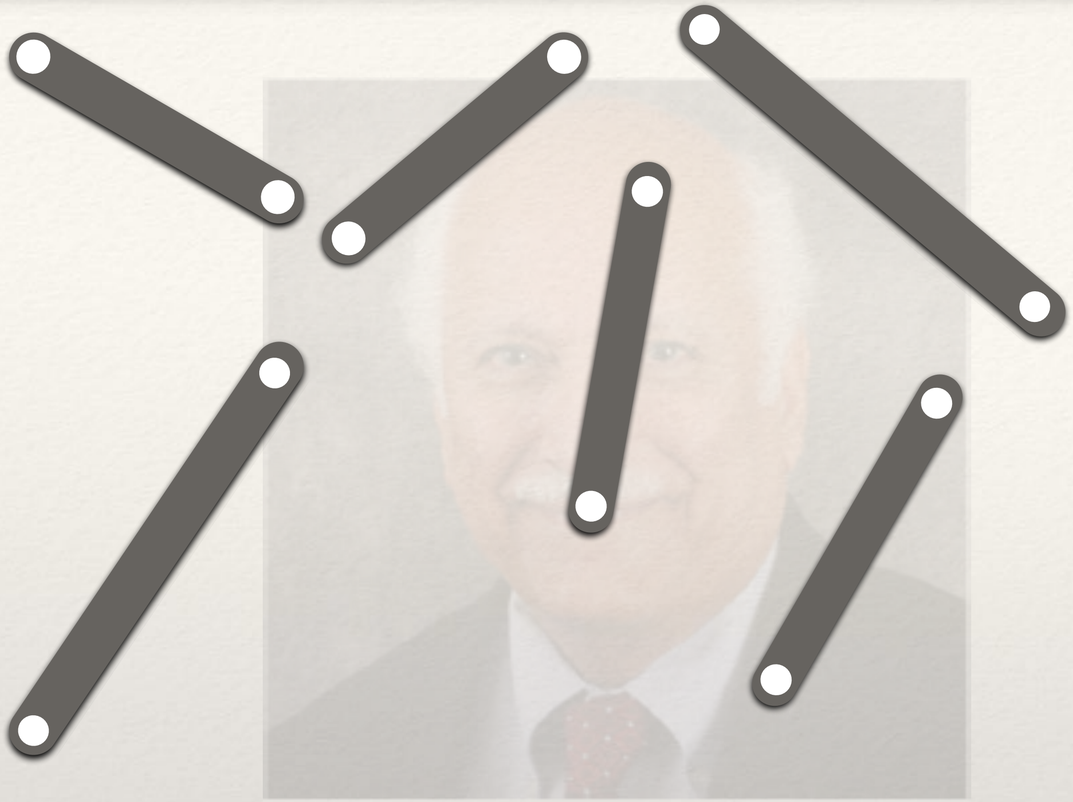
MOBILITY ANALYSIS

how many ways could this move?

how many ways, now, would this system move?

Compliant Mechanisms (ME 851)

Anupam Saxena
Professor
Indian Institute of Technology Kanpur



...

https://engineering.purdue.edu/ME/Seminars/2021/compliant-mechanisms-memory-lane-and-some-novel-and-exciting-applications/amidha.PNG

Prof. Ashok Midha

Grübler's (Mobility) Criterion

Planar Motion

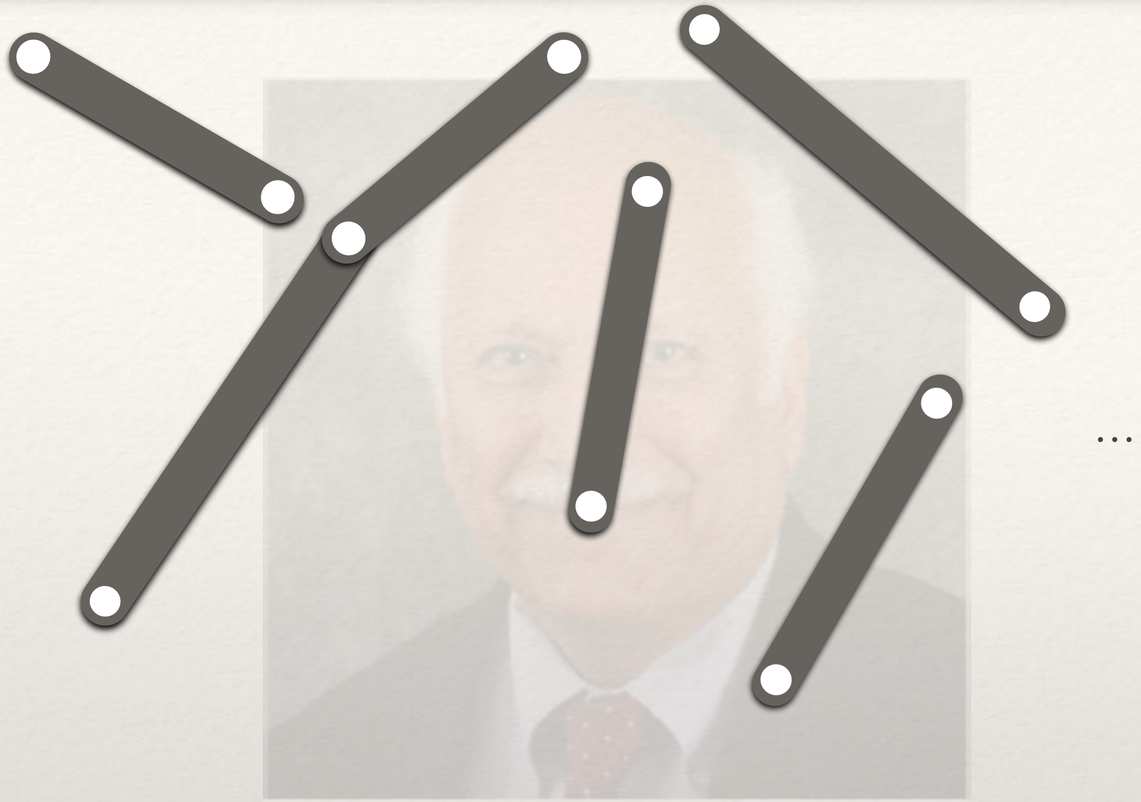
n rigid bodies

each body can translate and rotate

Net freedom in motion: $3n$

Compliant Mechanisms (ME 851)

Anupam Saxena
Professor
Indian Institute of Technology Kanpur



...

https://engineering.purdue.edu/ME/Seminars/2021/compliant-mechanisms-memory-lane-and-some-novel-and-exciting-applications/amidha.PNG

Prof. Ashok Midha

Grübler's (Mobility) Criterion

Planar Motion

n rigid bodies

each body can translate and rotate

Net freedom in motion: $3n$

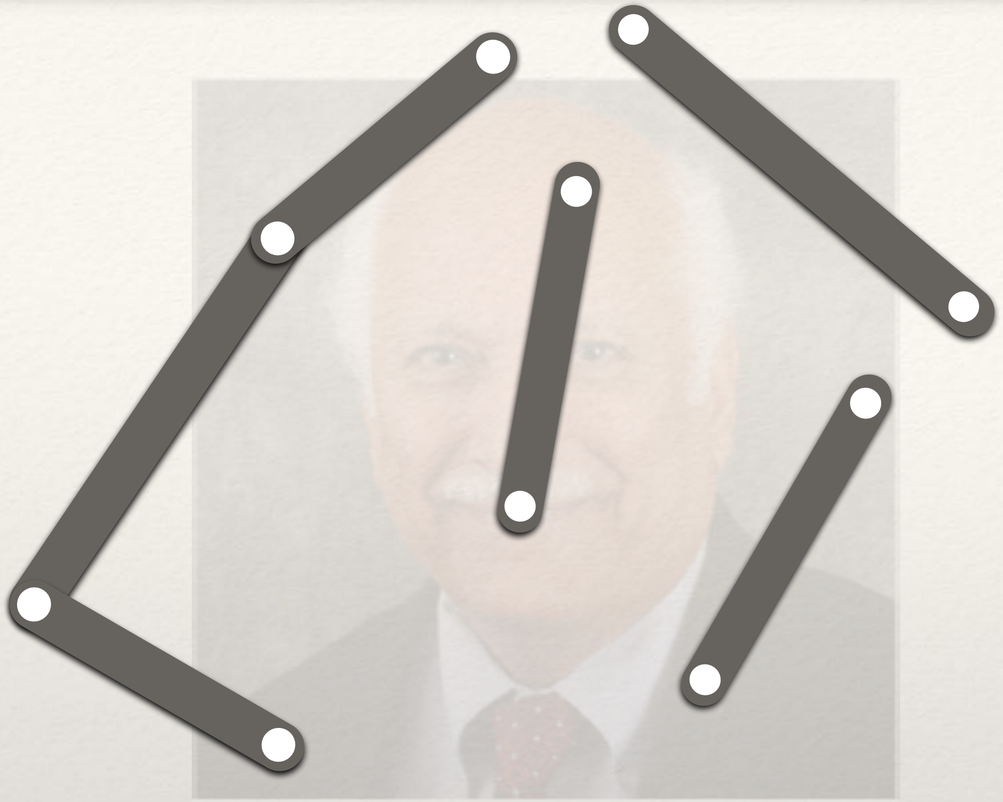
two motions arrested relative to a rigid body

a revolute joint (kinematic-pair) is created

Net freedom in motion: $3n - 2$

Compliant Mechanisms (ME 851)

Anupam Saxena
Professor
Indian Institute of Technology Kanpur



...

https://engineering.purdue.edu/ME/Seminars/2021/compliant-mechanisms-memory-lane-and-some-novel-and-exciting-applications/amidha.PNG

Prof. Ashok Midha

Grübler's (Mobility) Criterion

Planar Motion

n rigid bodies

each body can translate and rotate

Net freedom in motion: 3*n*

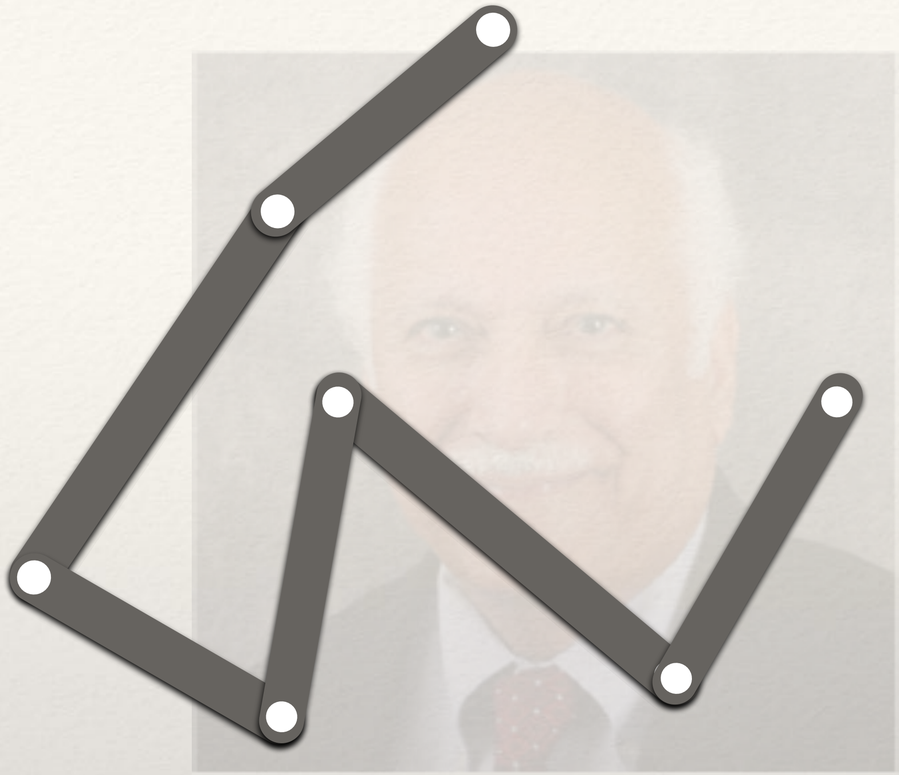
two more motions arrested relative to a rigid body

two revolute joints (kinematic-pairs) created

Net freedom in motion: 3*n* - *4*

Compliant Mechanisms (ME 851)

Anupam Saxena
Professor
Indian Institute of Technology Kanpur



...

https://engineering.purdue.edu/ME/Seminars/2021/compliant-mechanisms-memory-lane-and-some-novel-and-exciting-applications/amidha.PNG

Prof. Ashok Midha

Grübler's (Mobility) Criterion

Planar Motion

n rigid bodies

each body can translate and rotate

Net freedom in motion: $3n$

three more motions arrested relative to a rigid body

three additional revolute joints created

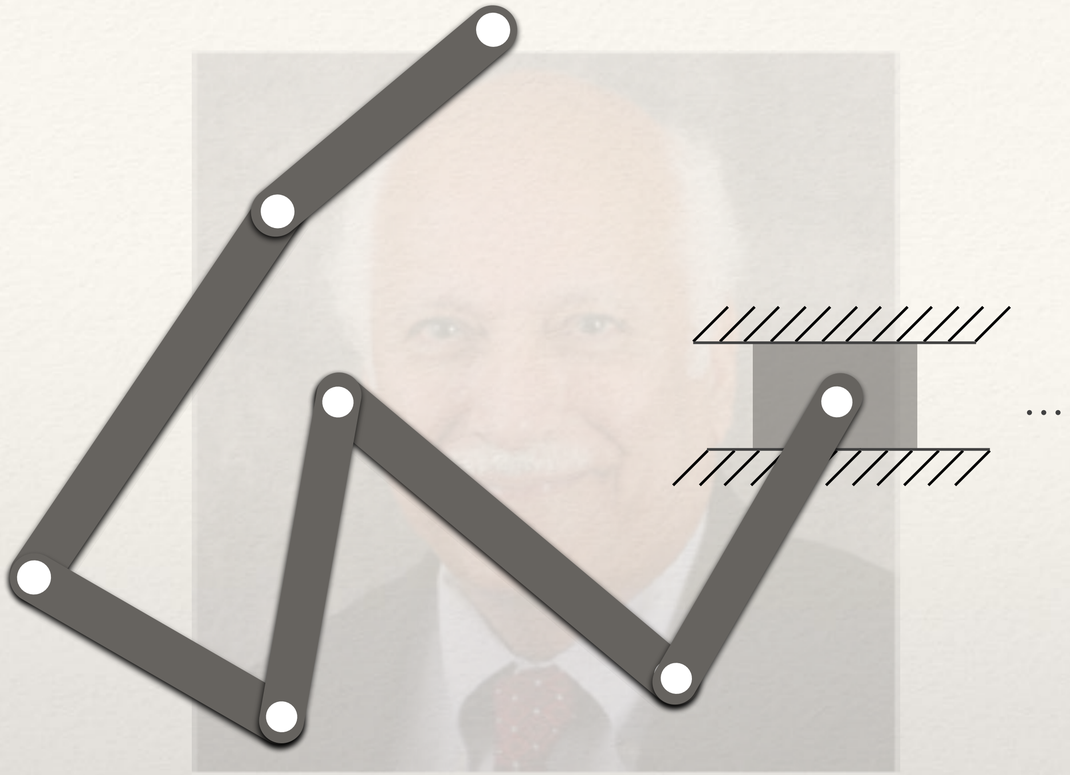
Net freedom in motion: $3n - 10$

In general, net freedom in motion: $3n - 2rp$

rp: revolute pairs

Compliant Mechanisms (ME 851)

Anupam Saxena
Professor
Indian Institute of Technology Kanpur



https://engineering.purdue.edu/ME/Seminars/2021/compliant-mechanisms-memory-lane-and-some-novel-and-exciting-applications/amidha.PNG

Prof. Ashok Midha

Grübler's (Mobility) Criterion

Planar Motion

n rigid bodies

each body can translate and rotate

Net freedom in motion: $3n$

In general, net freedom in motion: $3n - 2rp$

A link gets generated, which can only translate

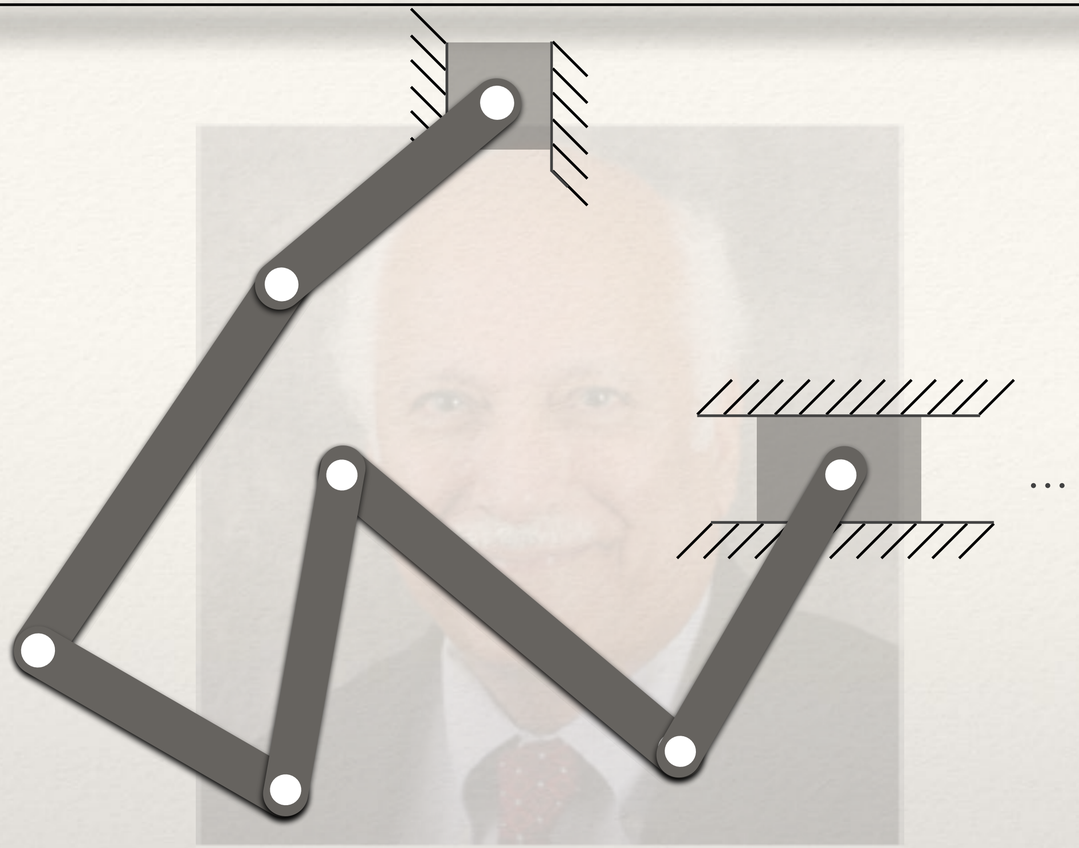
net freedom in motion: $3(n+1) - 2rp - 2$

$$3n - 2rp - 2$$

n: TOTAL number of rigid bodies

Compliant Mechanisms (ME 851)

Anupam Saxena
Professor
Indian Institute of Technology Kanpur



https://engineering.purdue.edu/ME/Seminars/2021/compliant-mechanisms-memory-lane-and-some-novel-and-exciting-applications/amidha.PNG

Prof. Ashok Midha

Grübler's (Mobility) Criterion

Planar Motion

n rigid bodies

each body can translate and rotate

Net freedom in motion: $3n$

In general, net freedom in motion:
$3n - 2rp - 2$

One more link gets generated, which can only translate

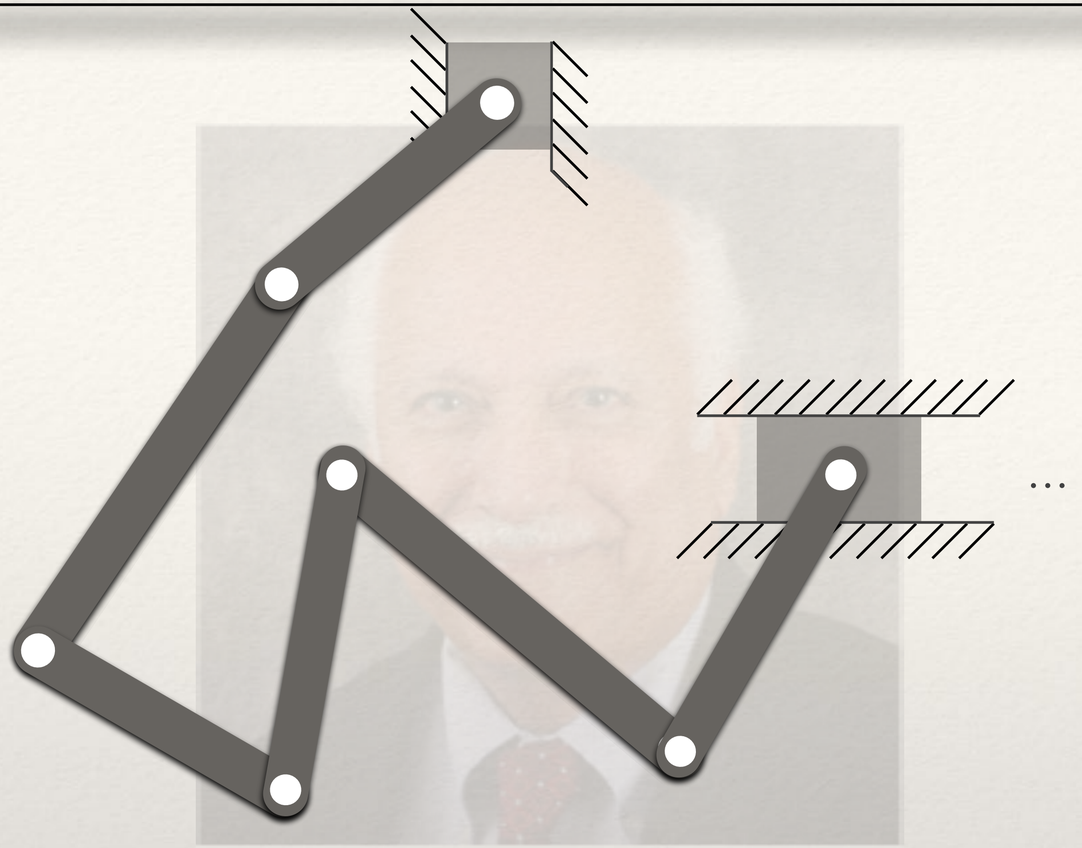
net freedom in motion: $3(n+1) - 2rp - 4$

$$3n - 2rp - 4$$

n: TOTAL number of rigid bodies

Compliant Mechanisms (ME 851)

Anupam Saxena
Professor
Indian Institute of Technology Kanpur



https://engineering.purdue.edu/ME/Seminars/2021/compliant-mechanisms-memory-lane-and-some-novel-and-exciting-applications/amidha.PNG

Prof. Ashok Midha

Grübler's (Mobility) Criterion

Planar Motion

n rigid bodies

each body can translate and rotate

Net freedom in motion: $3n$

In general, net freedom in motion:
$3n - 2rp - 2sp$

sp: slider pairs

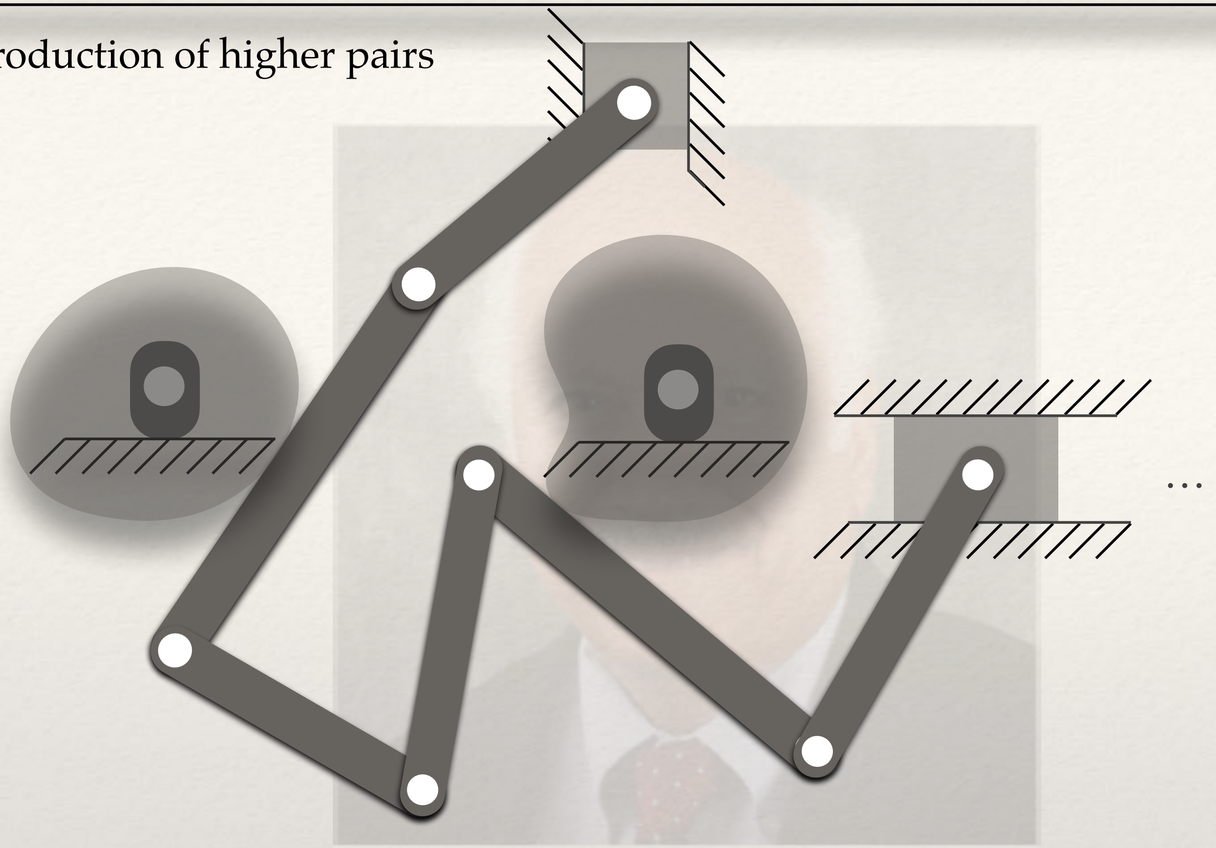
net freedom in motion: $3n - 2j_1$

$j_1 = rp + sp$ number of lower order pairs

Compliant Mechanisms (ME 851)

Anupam Saxena
Professor
Indian Institute of Technology Kanpur

Introduction of higher pairs



https://engineering.purdue.edu/ME/Seminars/2021/compliant-mechanisms-memory-lane-and-some-novel-and-exciting-applications/amidha.PNG

Prof. Ashok Midha

Grübler's (Mobility) Criterion

Planar Motion

n rigid bodies

each body can translate and rotate

net freedom in motion: $3n - 2j_1$

With each higher pair, one extra link or rigid-body introduced

Those many, i.e., j_2 motions reduced

net freedom in motion:

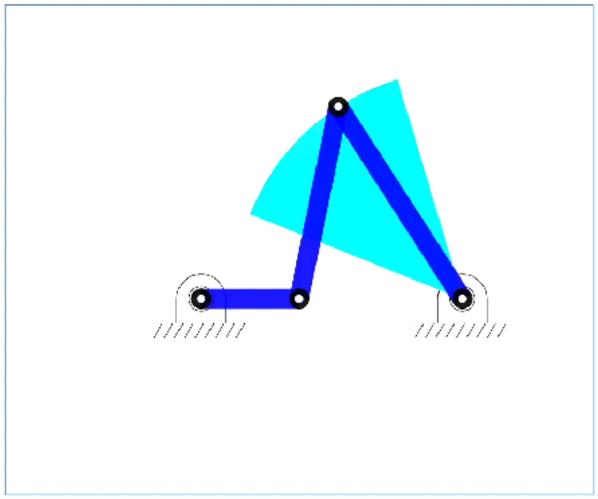
$$DOF : 3n - 2j_1 - j_2 - 3$$

to arrest 2T and 1R of the entire system

Compliant Mechanisms (ME 851)

Anupam Saxena
Professor
Indian Institute of Technology Kanpur

Some Examples



No. links: $n = 4$
No. joints: $j_1 = 4$

https://engineering.purdue.edu/ME/Seminars/2021/compliant-mechanisms-memory-lane-and-some-novel-and-exciting-applications/amidha.PNG

Prof. Ashok Midha

Grübler's (Mobility) Criterion

Planar Motion

n rigid bodies

each body can translate and rotate

net freedom in motion: $3n - 2j_1$

With each higher pair, one extra link or rigid-body introduced

Those many, i.e., j_2 motions reduced

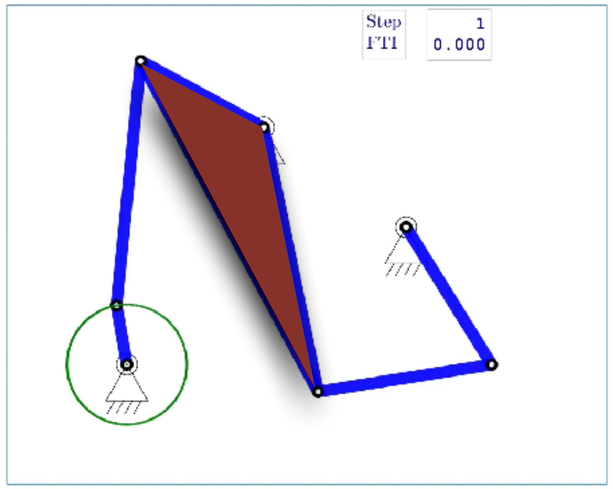
net freedom in motion:

$$DOF : 3(n-1) - 2j_1 - j_2$$

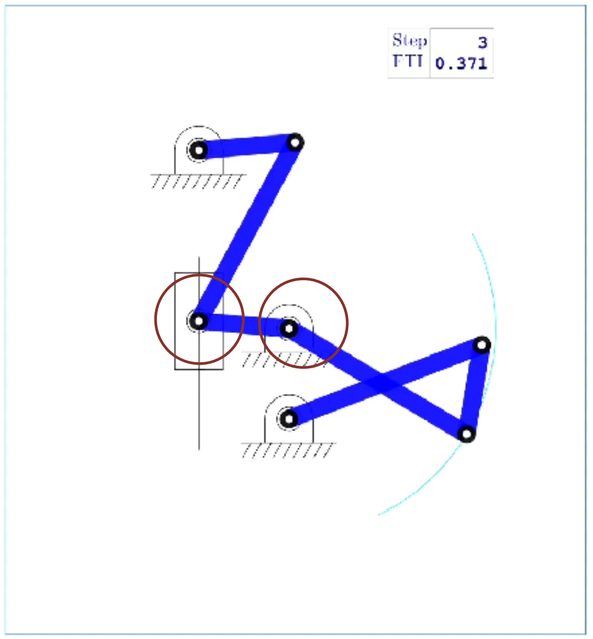
Compliant Mechanisms (ME 851)

Anupam Saxena
Professor
Indian Institute of Technology Kanpur

Some Examples



No. links: $n = 6$
No. joints: $j_1 = 7$



No. links: $n = 8$ No. joints: $j_1 = 10$

https://engineering.purdue.edu/ME/Seminars/2021/compliant-mechanisms-memory-lane-and-some-novel-and-exciting-applications/amidha.PNG

Prof. Ashok Midha

Grübler's (Mobility) Criterion

Planar Motion

n rigid bodies

each body can translate and rotate

net freedom in motion: $3n - 2j_1$

With each higher pair, one extra link or rigid-body introduced

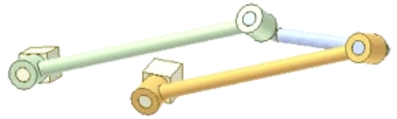
Those many, i.e., j_2 motions reduced

net freedom in motion:

$$DOF : 3(n-1) - 2j_1 - j_2$$

Compliant Mechanisms (ME 851)

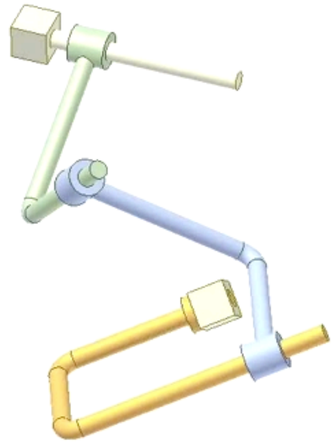
Anupam Saxena
Professor
Indian Institute of Technology Kanpur



Bennett 4R(revolute) mechanism

http://youtu.be/q433oAXwHuU

4L, $4j_1$: $DOF = 6(3) - 5(4) = -2$



RCCC mechanism

http://youtu.be/9mcEF2s8QZU

4L, $1j_1$, $3j_2$: $DOF = 6(3) - 5(1) - 4(3) = 1$

https://engineering.purdue.edu/ME/Seminars/2021/compliant-mechanisms-memory-lane-and-some-novel-and-exciting-applications/amidha.PNG

Prof. Ashok Midha

Opposite links: a, b, equal length

Opposite twist angles: A, B, equal but opposite signs

sinA/a = sinB/b

Kutzbach (Mobility) Criterion

Spatial Motion

straightforward extension

$DOF : 3(n-1) - 2j_1 - j_2$

n rigid bodies

j_1 joints restricting 5 relative motions

j_2 joints restricting 4 relative motions

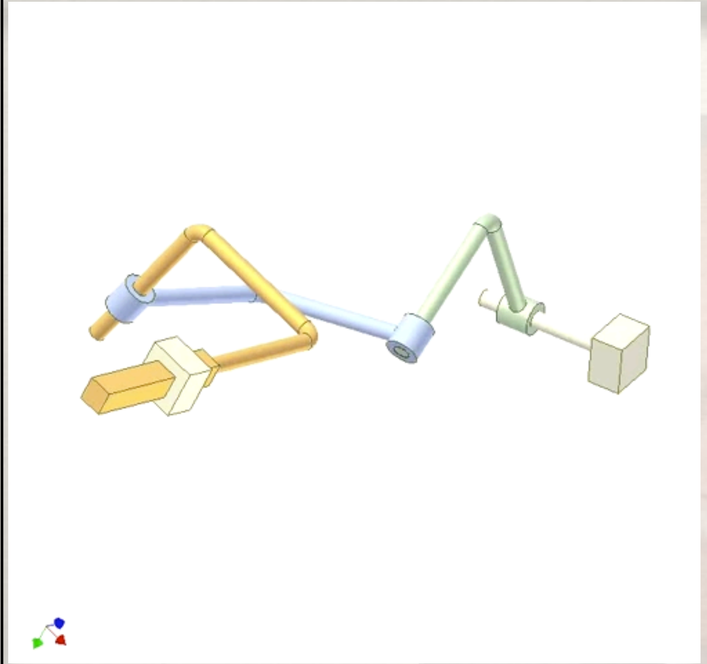
j_3 joints restricting 3 relative motions

j_5 joints restricting 1 relative motions

$DOF : 6(n-1) - 5j_1 - 4j_2 - 3j_3 - 2j_4 - j_5$

Compliant Mechanisms (ME 851)

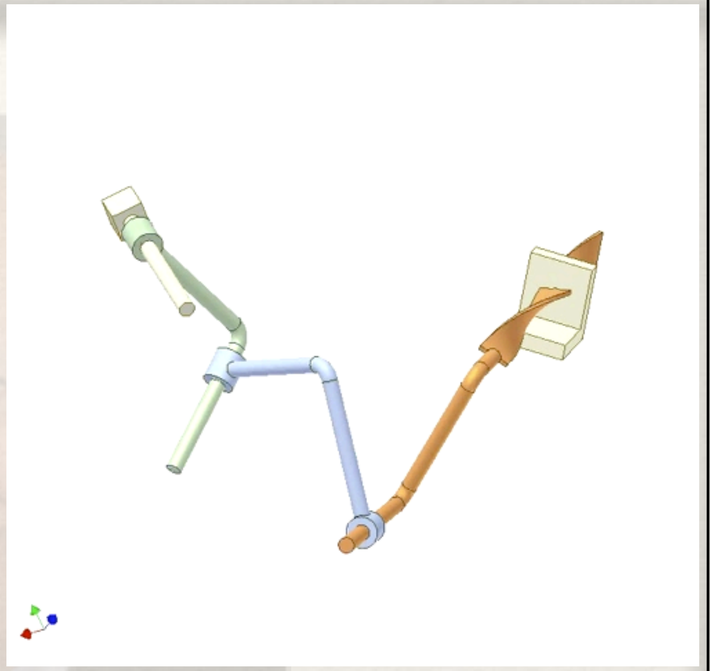
Anupam Saxena
Professor
Indian Institute of Technology Kanpur



PCCC mechanism

http://youtu.be/nK66IwNJG78

4L, $1j_1$, $3j_2$: $DOF = 6(3) - 5(1) - 4(3) = 1$



HCCC mechanism

http://youtu.be/aUILcT74mXM

4L, $1j_1$, $3j_2$: $DOF = 6(3) - 5(1) - 4(3) = 1$

https://engineering.purdue.edu/ME/Seminars/2021/compliant-mechanisms-memory-lane-and-some-novel-and-exciting-applications/amidha.PNG

Prof. Ashok Midha

Kutzbach (Mobility) Criterion

Spatial Motion

straightforward extension

$DOF : 3(n-1) - 2j_1 - j_2$

n rigid bodies

j_1 joints restricting 5 relative motions

j_2 joints restricting 4 relative motions

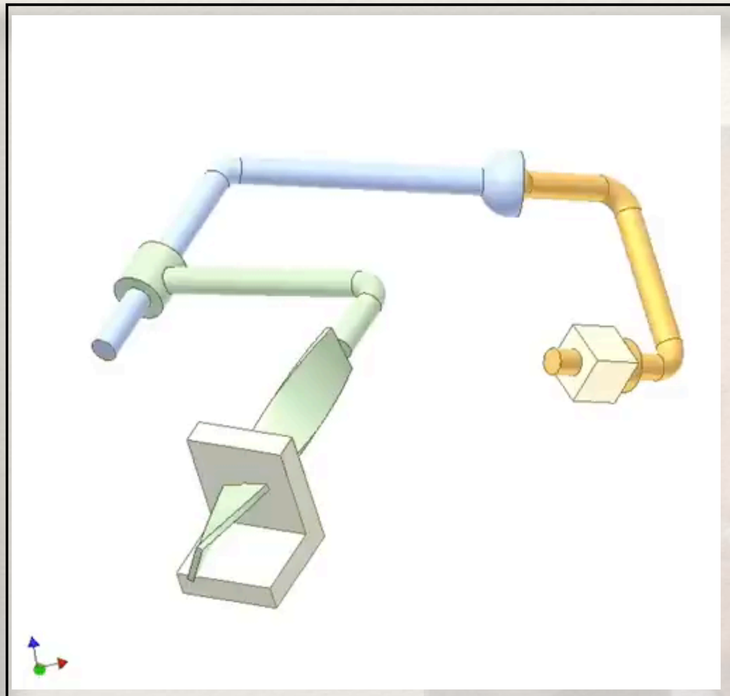
j_3 joints restricting 3 relative motions

j_5 joints restricting 1 relative motions

$DOF : 6(n-1) - 5j_1 - 4j_2 - 3j_3 - 2j_4 - j_5$

Compliant Mechanisms (ME 851)

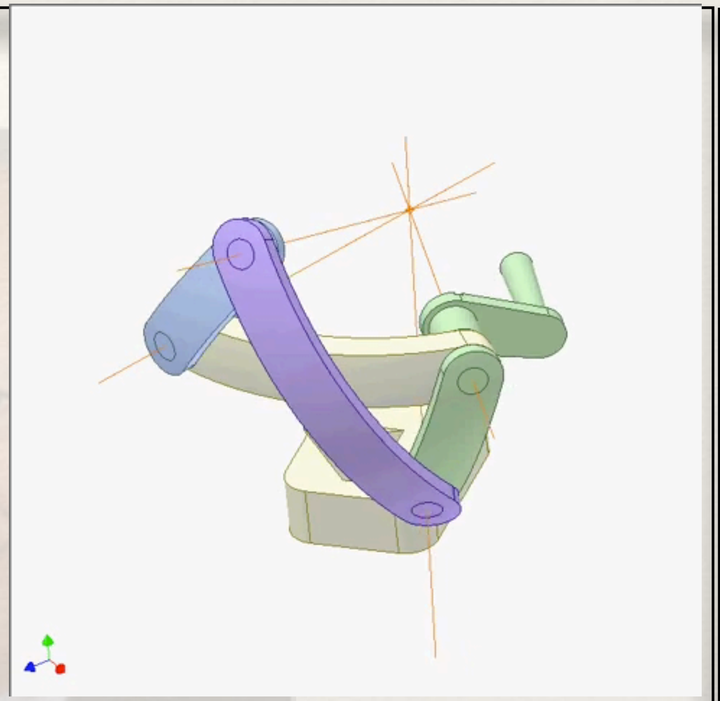
Anupam Saxena
Professor
Indian Institute of Technology Kanpur



RSCH mechanism

http://youtu.be/Gg8Q6nUZc1c

4L, $2j_1$, $1j_2$,$1j_3$: $DOF = 6(3) - 5(2) - 4(1) - 3(1) = 1$



Spherical 4R mechanism

http://www.youtube.com/watch?v=q0erDDuPO7w

4L, $4j_1$: $DOF = 6(3) - 5(4) = -2$

https://engineering.purdue.edu/ME/Seminars/2021/compliant-mechanisms-memory-lane-and-some-novel-and-exciting-applications/amidha.PNG

Prof. Ashok Midha

Axes of R joints cocentric

Kutzbach (Mobility) Criterion

Spatial Motion

straightforward extension

$DOF : 3(n-1) - 2j_1 - j_2$

n rigid bodies

j_1 joints restricting 5 relative motions

j_2 joints restricting 4 relative motions

j_3 joints restricting 3 relative motions

j_5 joints restricting 1 relative motions

$DOF : 6(n-1) - 5j_1 - 4j_2 - 3j_3 - 2j_4 - j_5$

Compliant Mechanisms (ME 851)

Anupam Saxena
Professor
Indian Institute of Technology Kanpur