

SEM0317 - Aula 1

Revisão Básica de Cinemática e Álgebra

Prof. Dr. Marcelo Becker

SEM - EESC - USP

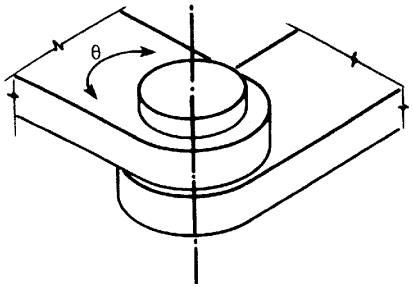
Sumário da Aula

- **Juntas e Elos**
- Cadeias Cinemáticas
- Cálculo de Graus de Liberdade
- Exercícios Recomendados
- Bibliografia Recomendada

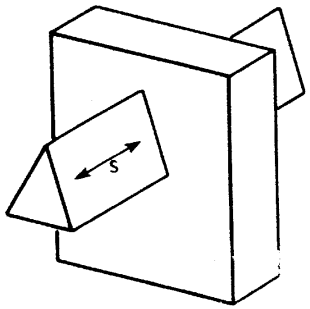
Juntas e Elos

- Juntas *(Joints)*

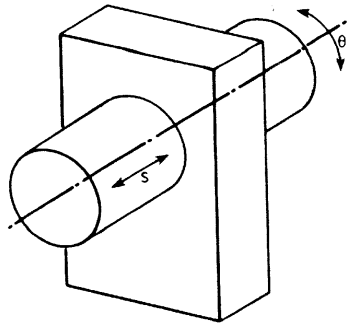
<u>Definição</u>: elemento que conecta 2 corpos (elos - links) e que permite a transmissão de movimento, força ou torque. Atuam como restrições geométricas.



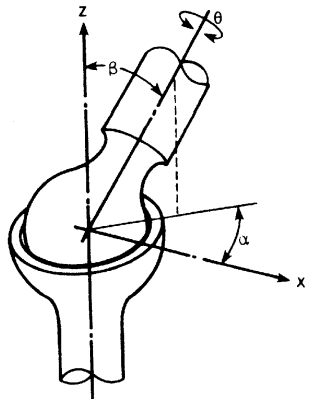
Rotacional



Prismática



Cilíndrica



Esférica

Juntas e Elos

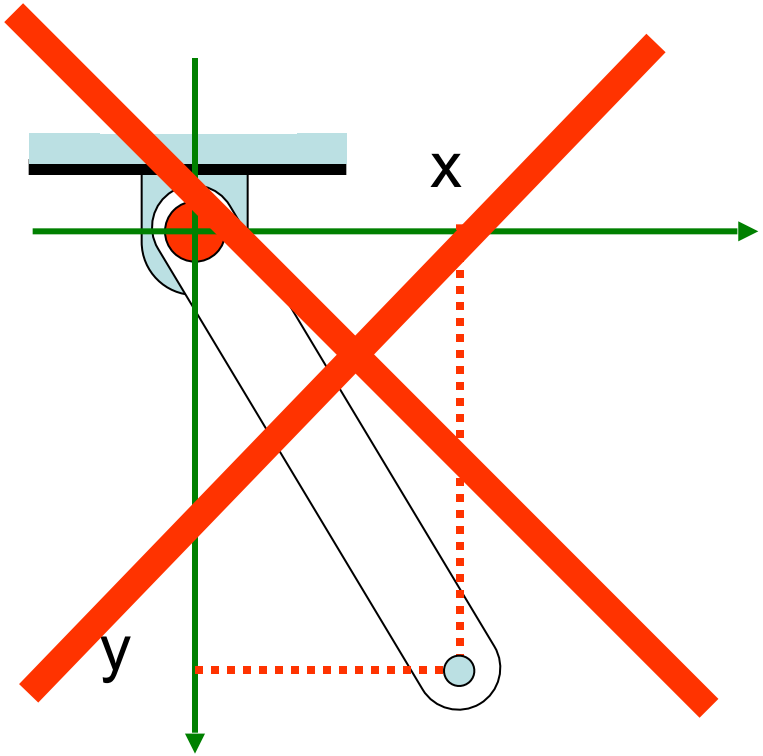
- O que significa Grau de Liberdade?

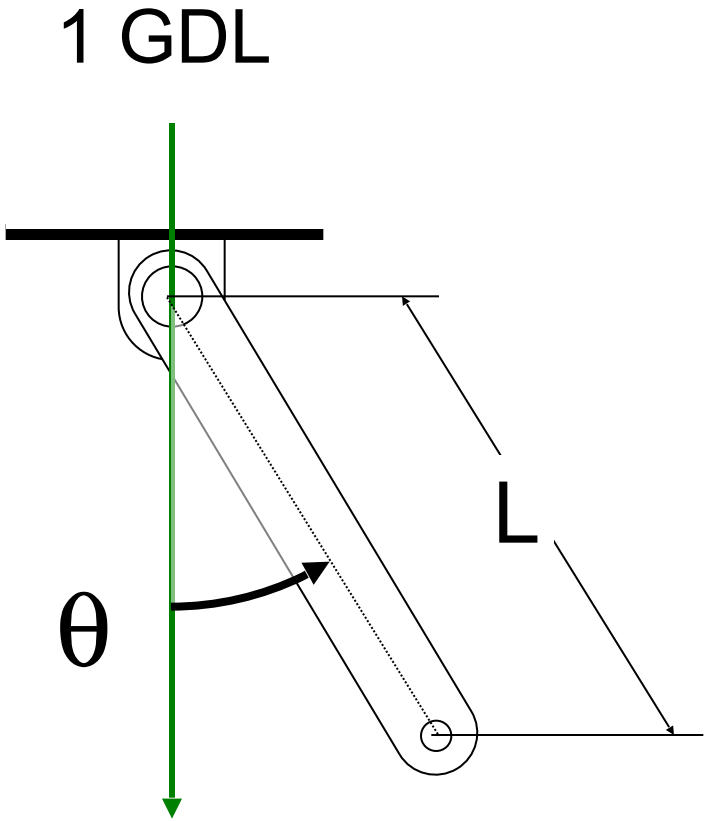
  Definição: é o número de parâmetros independentes que são necessários para se definir a posição de um corpo no espaço em qualquer instante.

- GDL ou DoF (*Degree of Freedom*)

Juntas e Elos

- Quais são os GDLs?



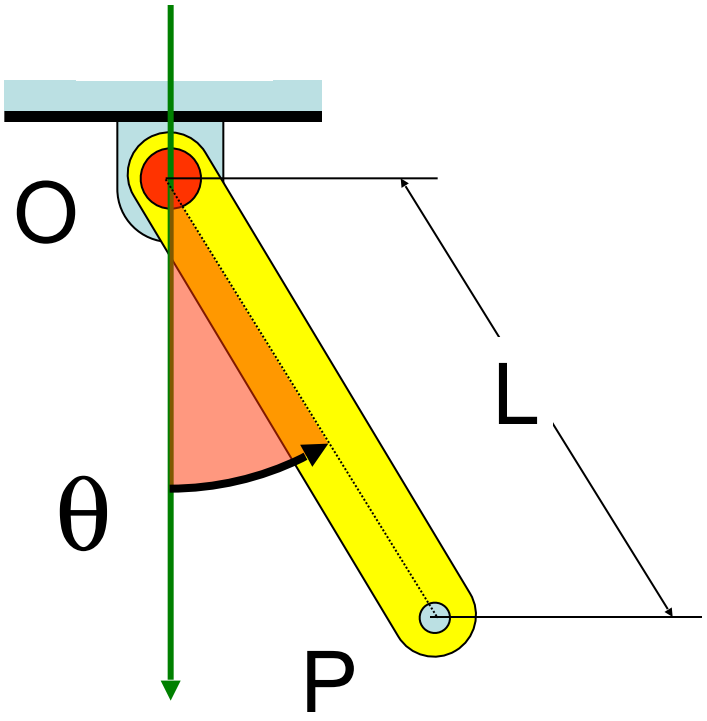


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Juntas e Elos

- Equações de Posição:

1 GDL

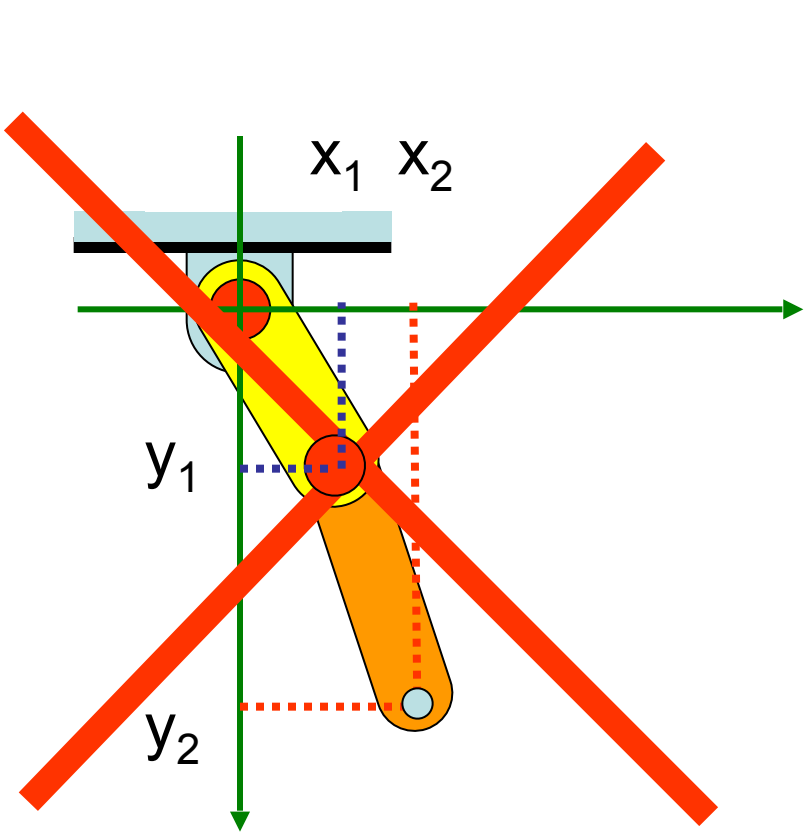


$$\overrightarrow{P} = L.e^{i\theta}$$

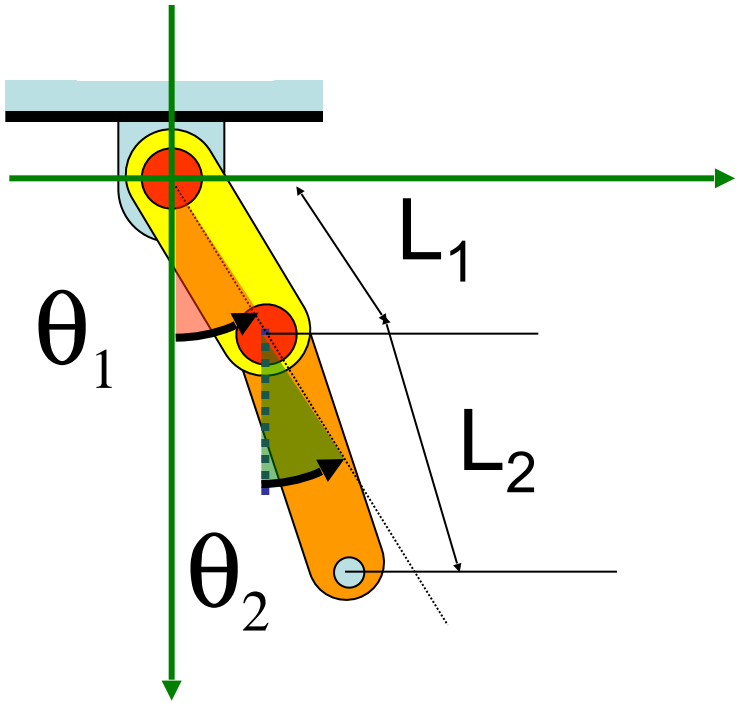
$$\overrightarrow{P} = L.(\sin\theta\,\vec{i} + \cos\theta\,\vec{j})$$

Juntas e Elos

- Quais são os GDLs?



2 GDL

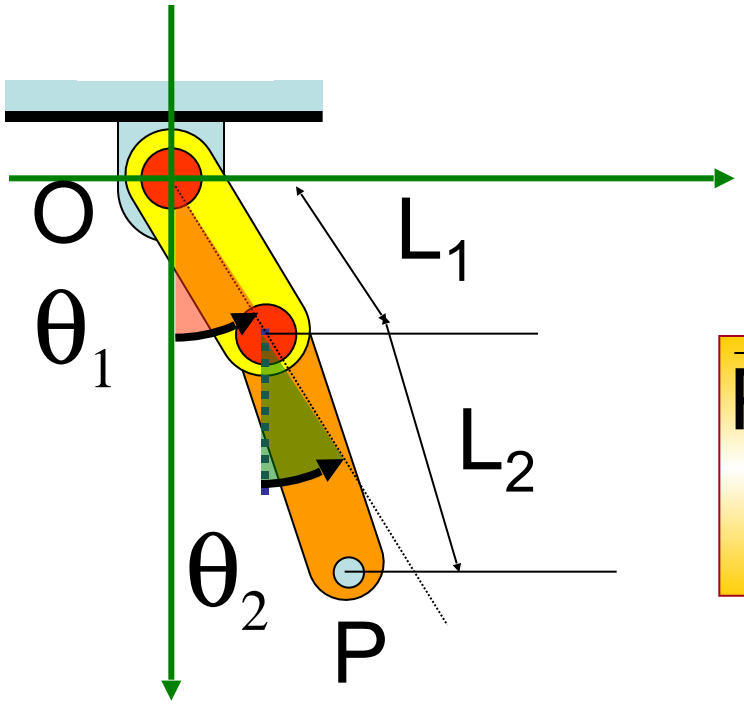


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Juntas e Elos

- Equações de Posição:

2 GDL

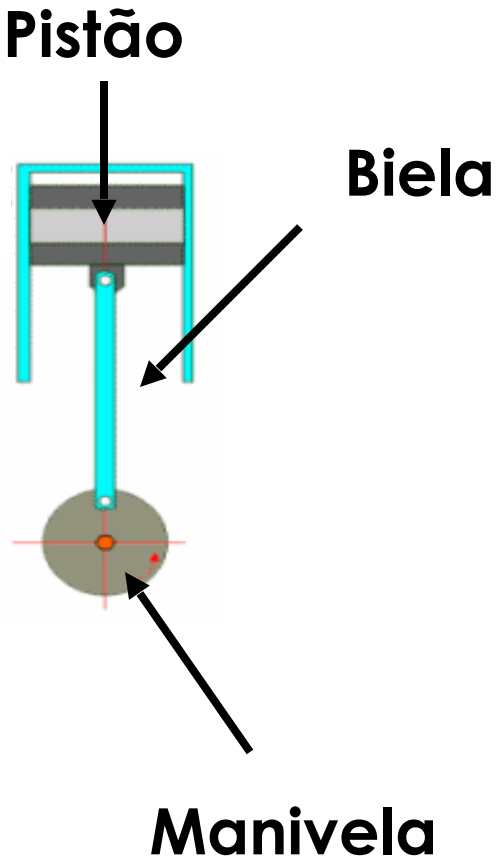


$$\overrightarrow{P} = L_1.e^{i\theta_1} + L_2.e^{i\theta_2}$$

$$\overrightarrow{P} = L_1.(\sin\theta_1\,\vec{i} + \cos\theta_1\,\vec{j}) + \ldots$$
$$L_2.(\sin\theta_2\,\vec{i} + \cos\theta_2\,\vec{j})$$

Juntas e Elos

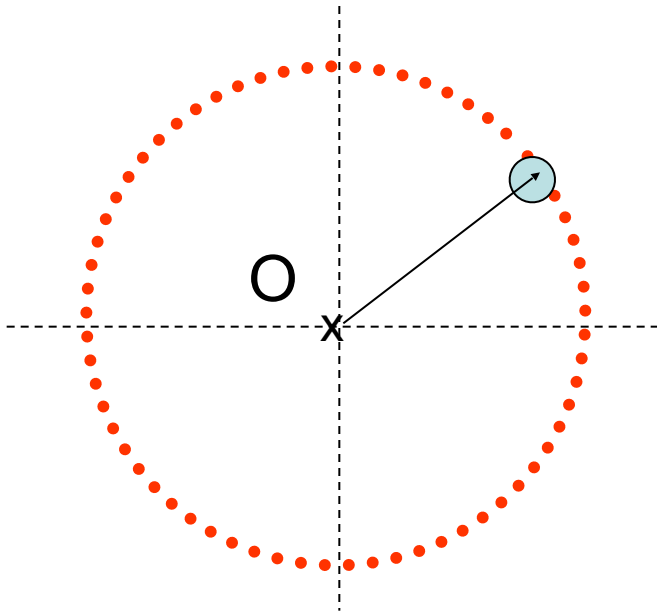
- Tipos de Movimento
  - Rotação Pura
  - Translação Pura
  - Movimento Complexo
    - Rotação + Translação



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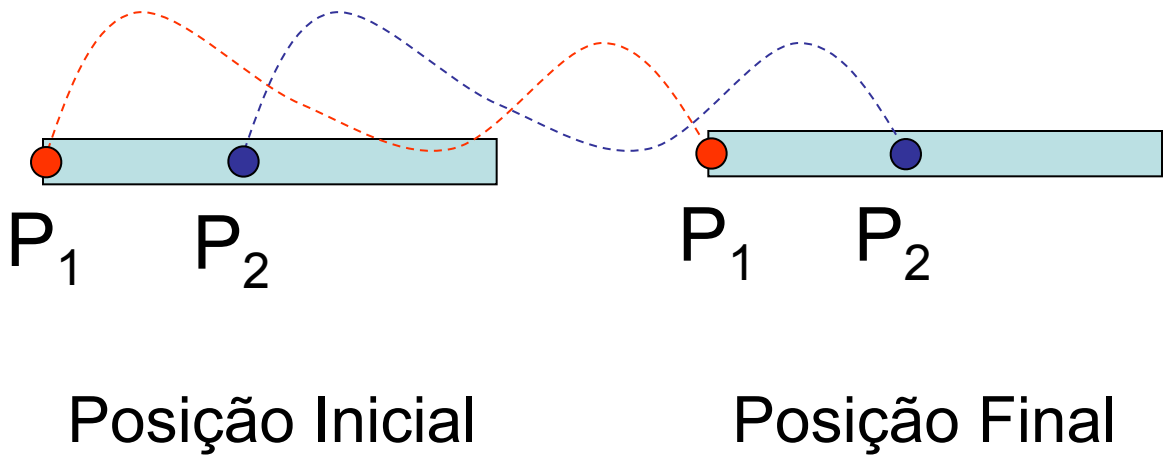
Juntas e Elos

- Rotação Pura
  - Todos os pontos do corpo descrevem trajetórias circulares



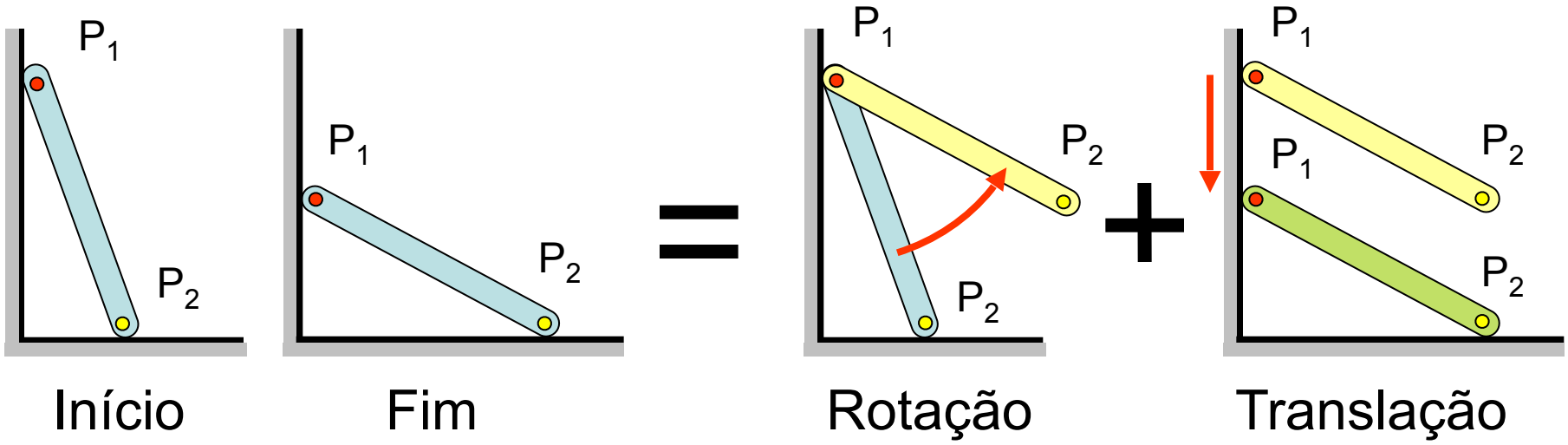
Juntas e Elos

- Translação Pura
  - Todos os pontos do corpo descrevem trajetórias paralelas (curvas ou retas)



Juntas e Elos

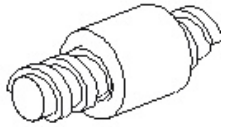
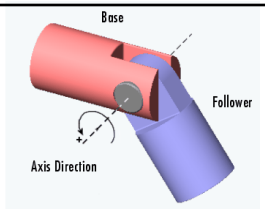
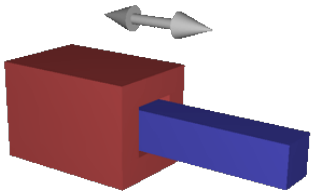
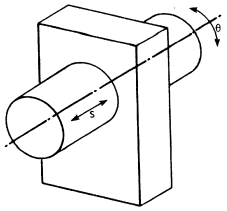
- Movimento Complexo
  - Pode ser descrito como a combinação de rotação e translação



Juntas e Elos

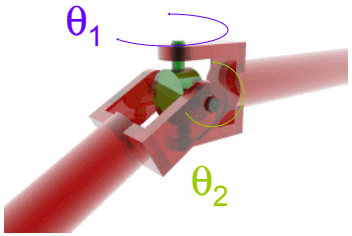
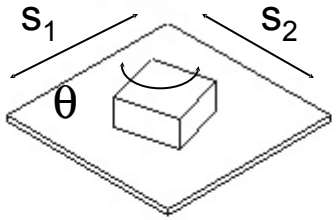
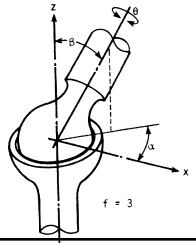
- Grande parte dos mecanismos atuais possui movimento planar
  - Movimento de todos os pontos são trajetórias em planos paralelos
- Mecanismos com movimento 3D:
  - Mecanismos Espaciais
  - Durante um longo período:
    - junta universal
    - engrenagens cônicas

Juntas e Elos

Tipo	Símbolo	Esquema	GDL	β
Helicoidal	**H**		**1**	θ
Rotação	**R**		**1**	θ
Prismática	**P**		**1**	**s**
Cilíndrica	**C**		**2**	θ **s**

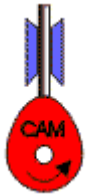
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Juntas e Elos

Tipo	Símbolo	Esquema	GDL	β
Universal	**T**		**2**	$\theta_1 \theta_2$
Plana	**E**		**3**	**θ s1 s2**
Esférica	**S**		**3**	$\theta \psi \phi$

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Juntas e Elos

Tipo	Símbolo	Esquema	GDL	β
Contato	**Co**		**1**	**Rotação SEM Escorrega-mento**
Engrenagem	**Eng**		**2**	**Rotação com Escorrega-mento**
Came - Seguidor	**CS**		**2**	**Translação com**

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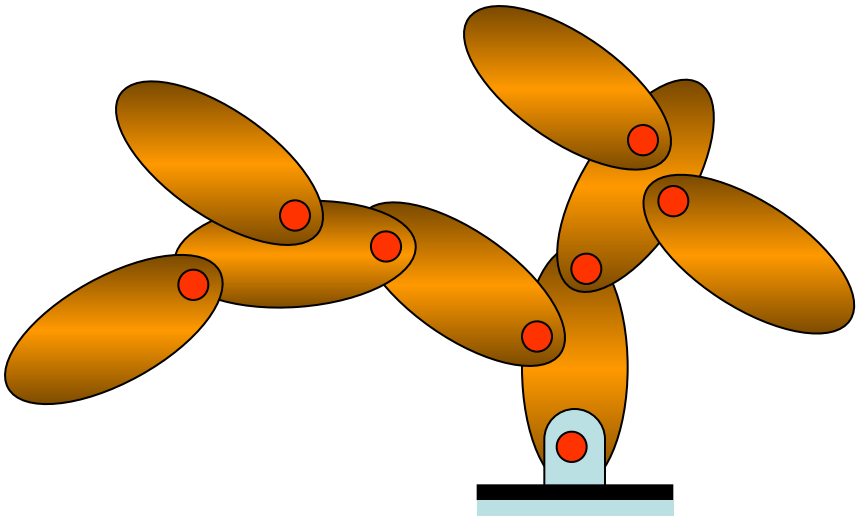
Sumário da Aula

-
- **Cadeias Cinemáticas**
- Cálculo de Graus de Liberdade
- Exercícios Recomendados
- Bibliografia Recomendada

Cadeias Cinemáticas

Topologias

- Cadeias Abertas
  - A trajetória entre 2 corpos é única
  - Excluindo o solo, o número de corpos é igual ao número de juntas



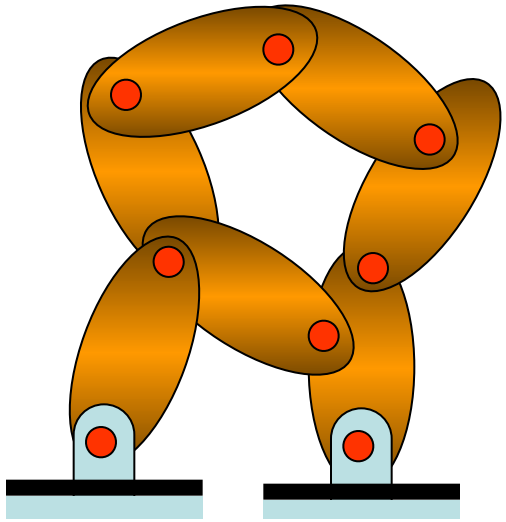


Cadeias Cinemáticas

Topologias

- Cadeias Fechadas
  - Loops

$$n_L = n_J - n_B$$



- Onde:

  n_L: Número de Loops

  n_J: Número de Juntas

  n_B: Número de Corpos (excluindo o solo)

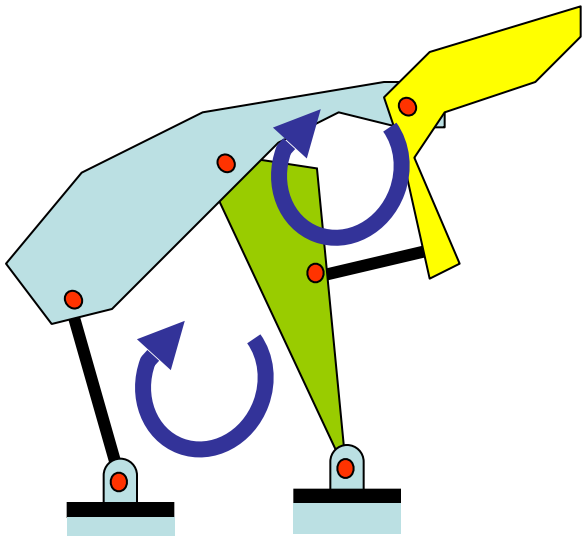
Cadeias Cinemáticas

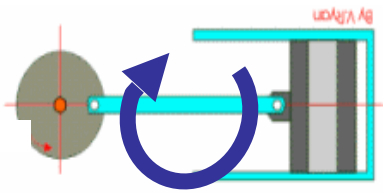
Topologias

- Cadeias Fechadas - Exemplos

$$n_L = n_J - n_B$$







Cadeias Cinemáticas

Topologias

- Cadeias Parcialmente Fechadas - Mistas

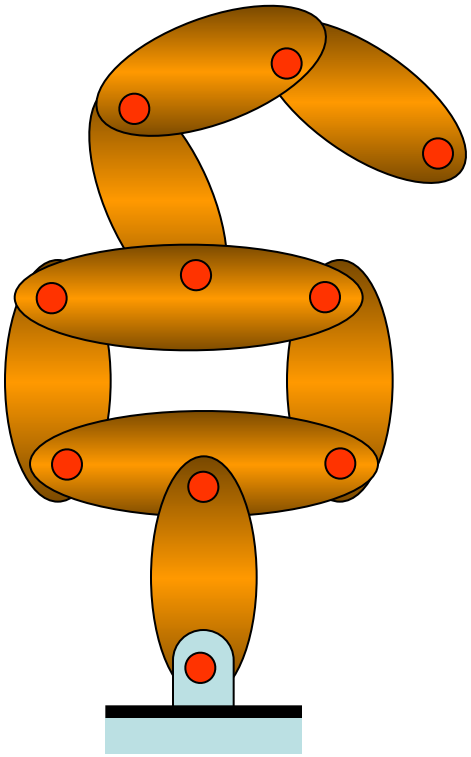




ABB IRB 2400



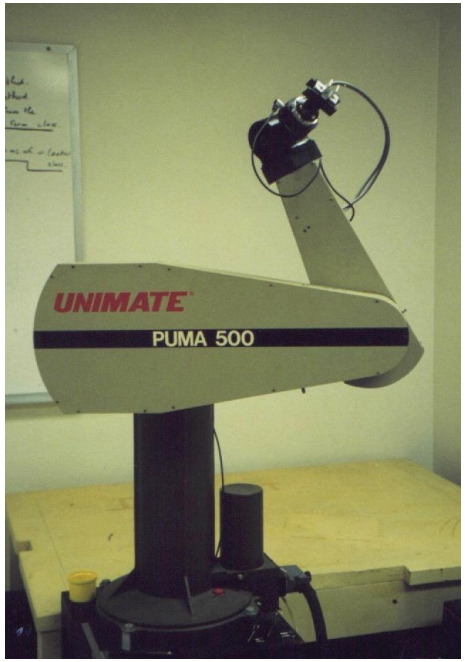
Kawasaki XZ 165L

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Cadeias Cinemáticas

Topologias

Manipuladores em Série e em Paralelo



PUMA 500

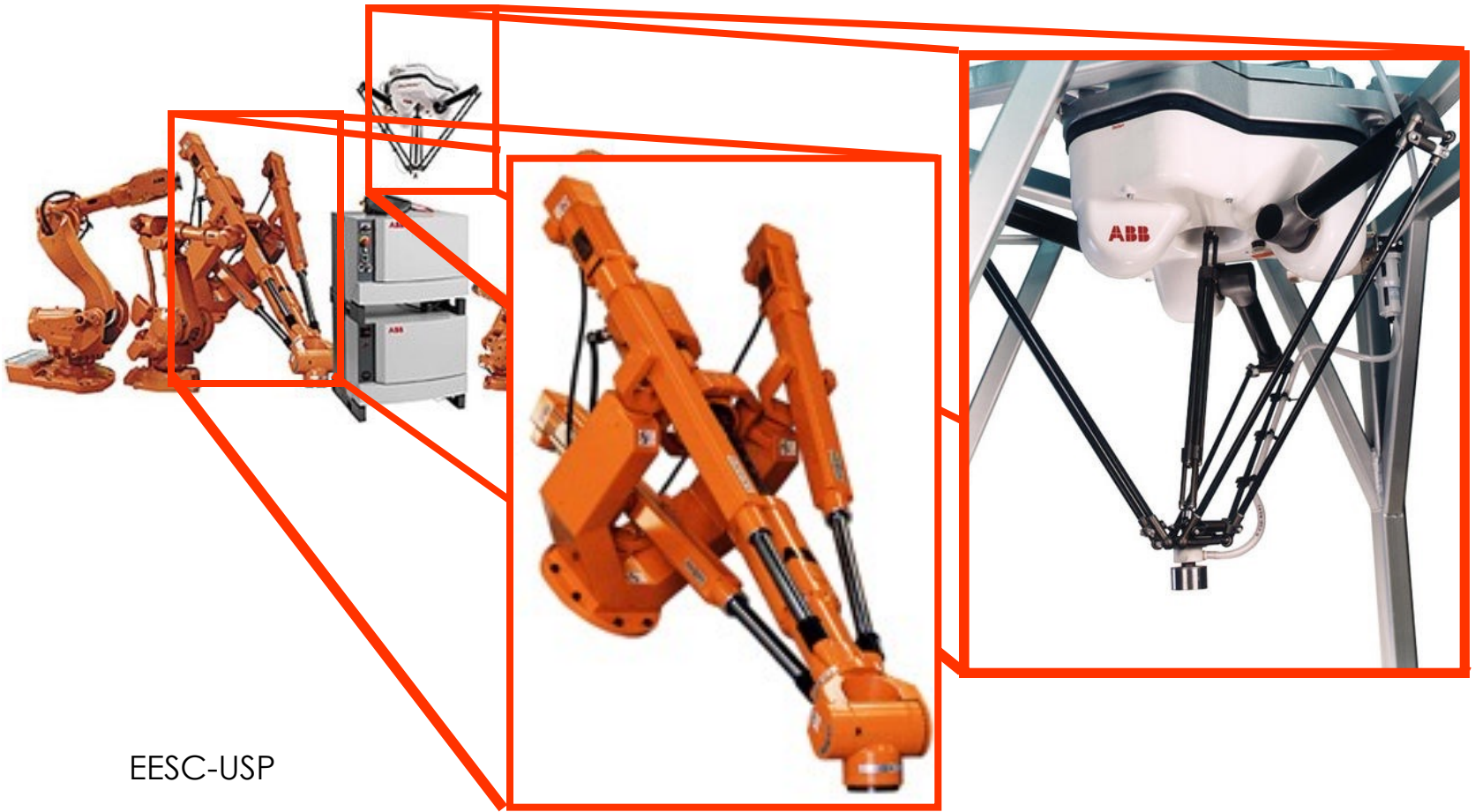


Hexapod

Cadeias Cinemáticas

Topologias

Manipuladores em Série e em Paralelo



Cadeias Cinemáticas

Topologias

Manipuladores em Série e em Paralelo

https://www.youtube.com/watch?v=BmFPIZU-cvc

https://www.youtube.com/watch?v=hLB2WuPMeI0

https://www.youtube.com/watch?v=wg8YYuLLoM0

https://www.youtube.com/watch?v=Mr7U9pQtwq8

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Sumário da Aula

-
-
- **Cálculo de Graus de Liberdade**
- Exercícios Recomendados
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Cálculo de Graus de Liberdade

- Critério de Kutzbach para mecanismos planos:

$$M = 3.(B-1) - 2.n_{J1} - n_{J2}$$

- Onde:

  M: Número de GDLs

  B: Número de Total de Corpos (incluindo o solo)

  n_{J1}: Número de Juntas com 1 GDL

  n_{J2}: Número de Juntas com 2 GDLs

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Cálculo de Graus de Liberdade

- Se:

  M = 0 : Sistema Estático

  M > 0 : Sistema com "M" graus de liberdade

  M < 0 : Sistema Hiperestático

Cálculo de Graus de Liberdade

- Não considerando o solo:

$$M = 3.n_B - \sum_{i=1}^{n_J} (3 - f_i)$$

- Onde:

  M: Número de GDLs

  n_B: Número de Corpos (excluindo o solo)

  n_J: Número de Juntas

  f_i: GDL da junta i

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Cálculo de Graus de Liberdade

Para mecanismos planos: $\lambda = 3$

$$M = \lambda(n - n_j - 1) + \sum_{i=1}^{n_j} f_i$$

- Onde:

  M: Número de GDLs

  n: Número de Corpos (incluindo o solo)

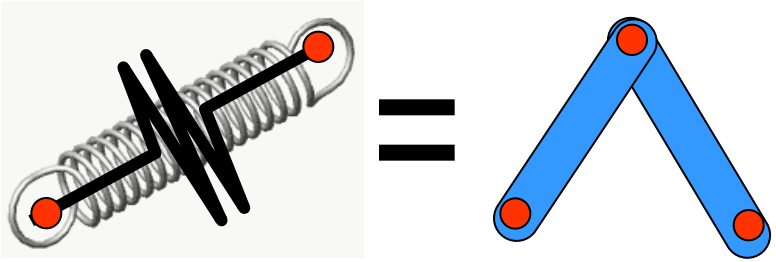
  n_j: Número de Juntas

  f_i: GDL da junta i

Cálculo de Graus de Liberdade

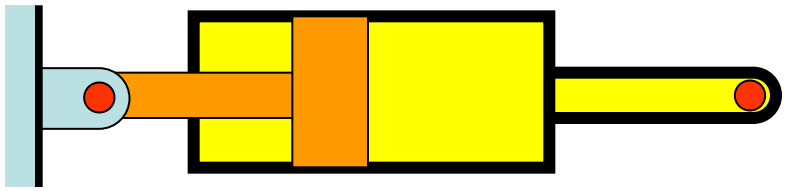
Cuidados na modelagem...

Molas



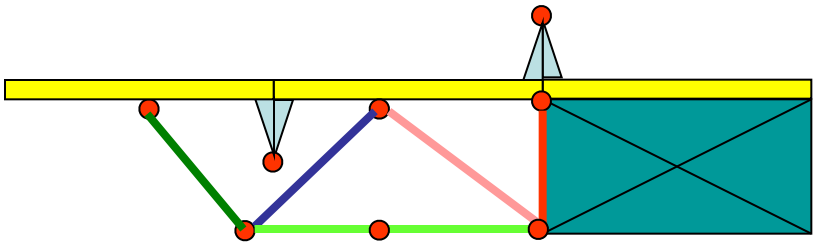
Sistemas Hidráulicos e Pneumáticos

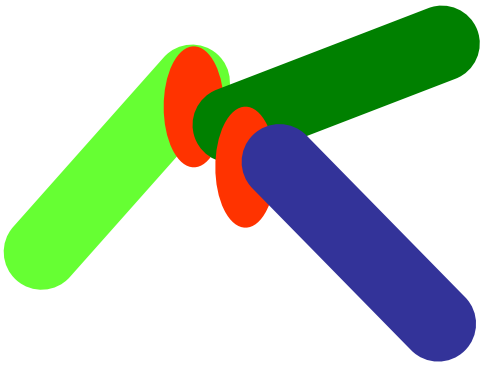


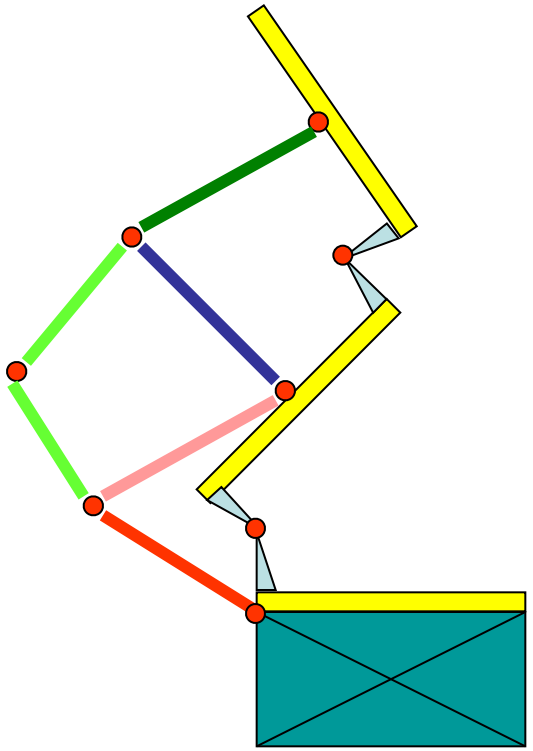


Cálculo de Graus de Liberdade

Exemplo: Painel Solar em Satélite...



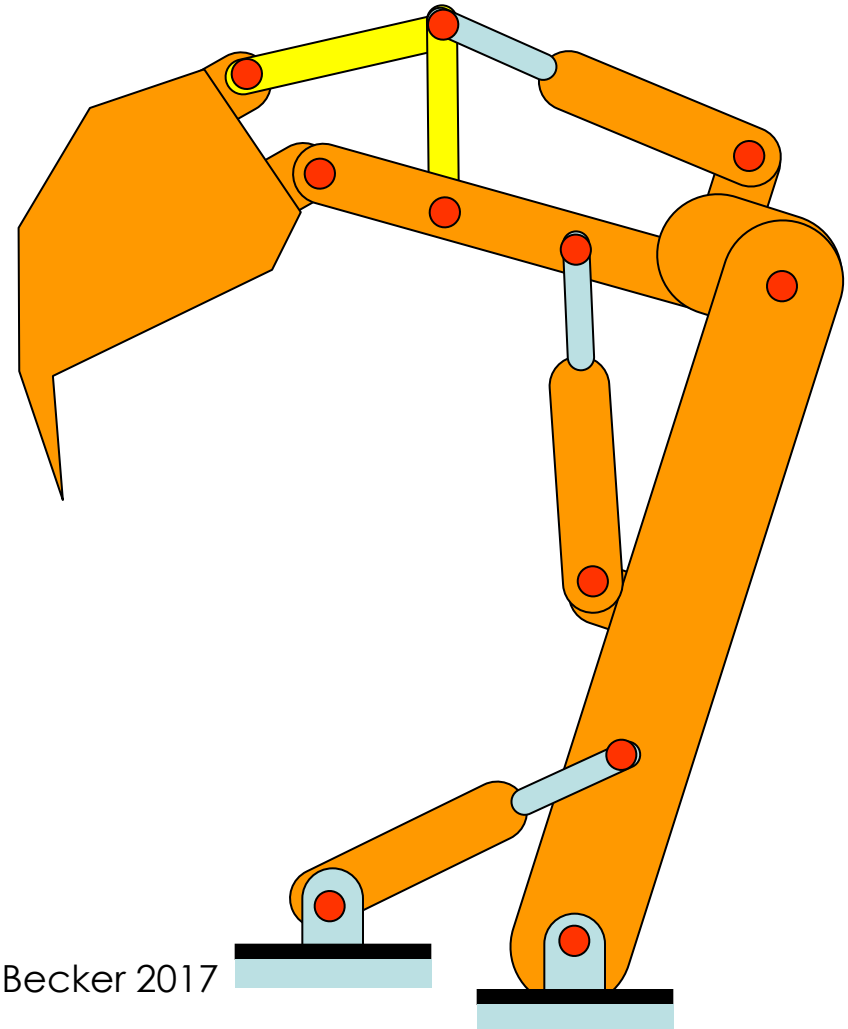




Cálculo de Graus de Liberdade

Exemplo: Retro-escavadeira...





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Cálculo de Graus de Liberdade

Para mecanismos espaciais:

$$M = 6n_B - \sum_{i=1}^{n_j} (6 - f_i)$$

- Onde:

  M: Número de GDLs

  n_B: Número de Corpos (excluindo o solo)

  n_j: Número de Juntas

  f_i: GDL da junta i

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Cálculo de Graus de Liberdade

Para mecanismos espaciais: $\lambda = 6$

$$M = \lambda(n - n_j - 1) + \sum_{i=1}^{n_j} f_i$$

- Onde:

  M: Número de GDLs

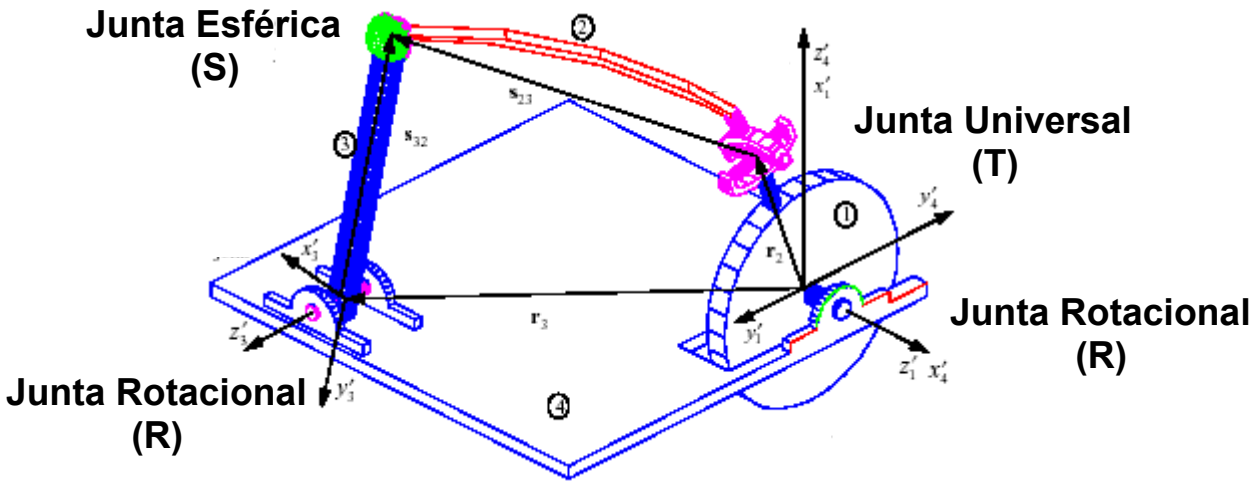
  n: Número de Corpos (incluindo o solo)

  n_j: Número de Juntas

  f_i: GDL da junta i

Cálculo de Graus de Liberdade

- Mecanismos Espaciais:
  - Podem ser classificados em função dos tipos de juntas
    - p.e.: 4 barras RSTR

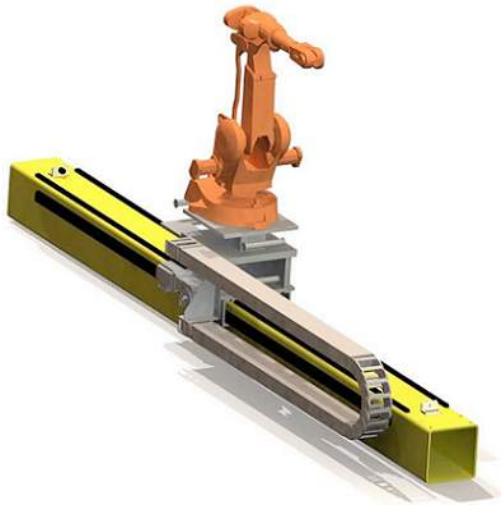


Cálculo de Graus de Liberdade



ABB IRB 2400





Cálculo de Graus de Liberdade



ABB IRB 940 Tricept

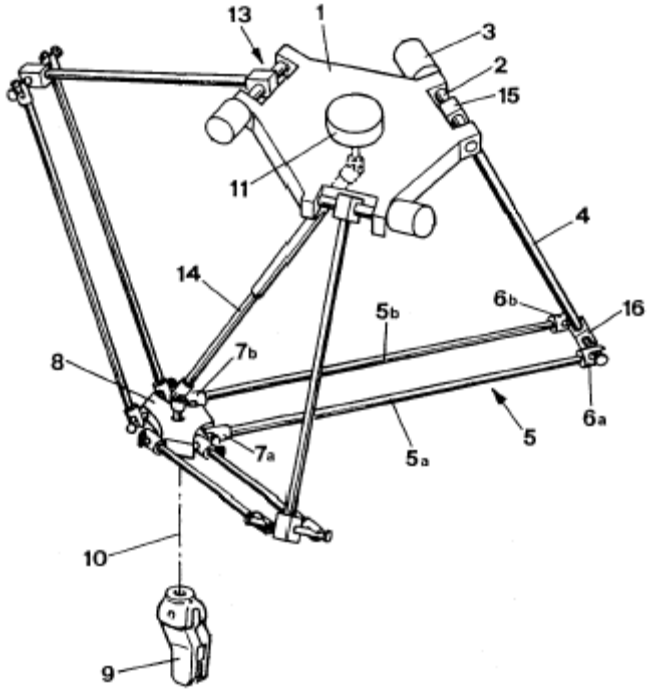


Robô Tricept
US patent No. 4,732,525

Cálculo de Graus de Liberdade



ABB IRB 340

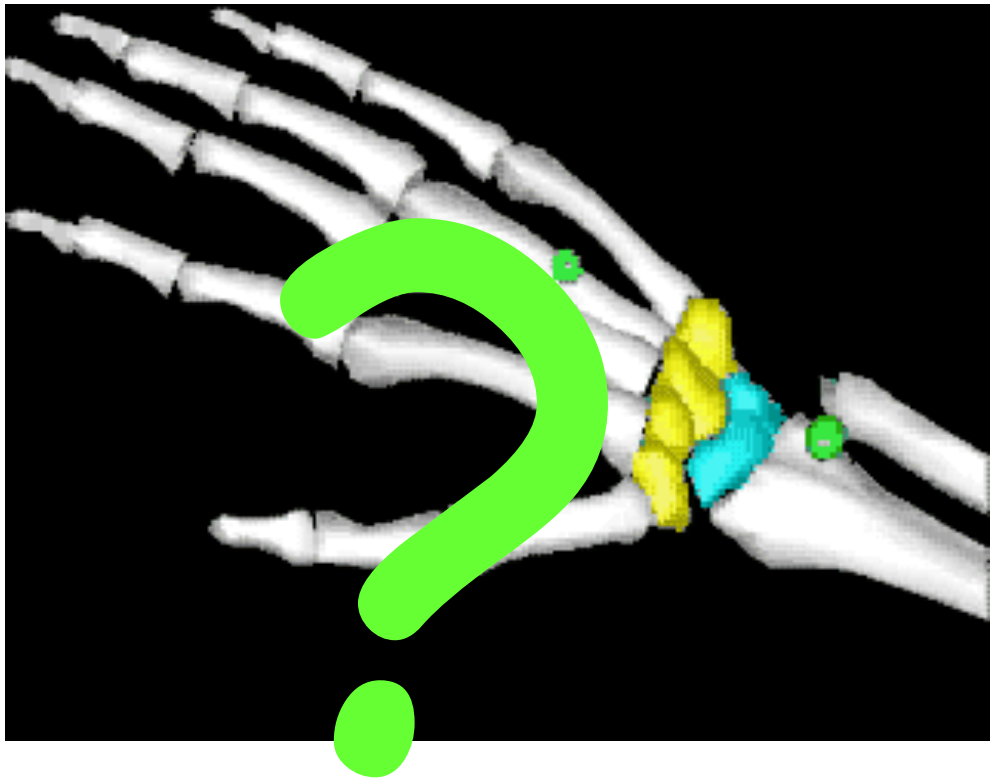


Robô Delta de Clavel (EPFL)
US patent No. 4,976,582

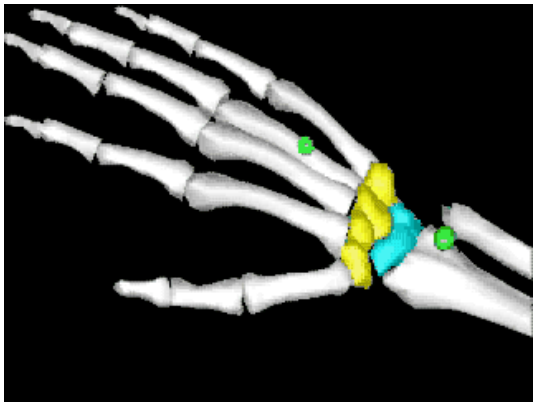
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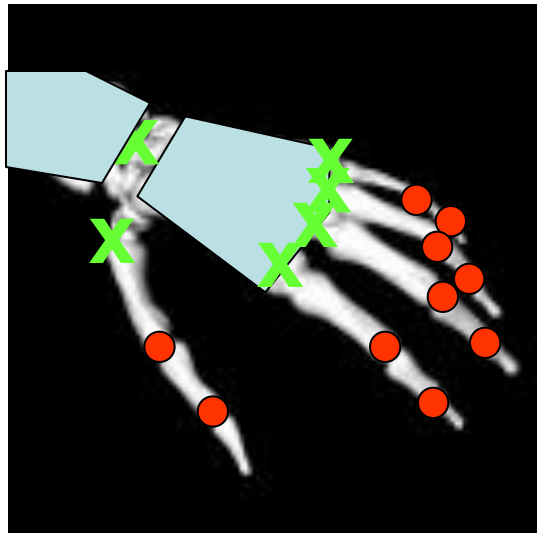
Cálculo de Graus de Liberdade

Quantos GDLs possui uma mão?



Cálculo de Graus de Liberdade





$$M = \lambda(n - n_j - 1) + \sum_{i=1}^{n_j} f_i$$



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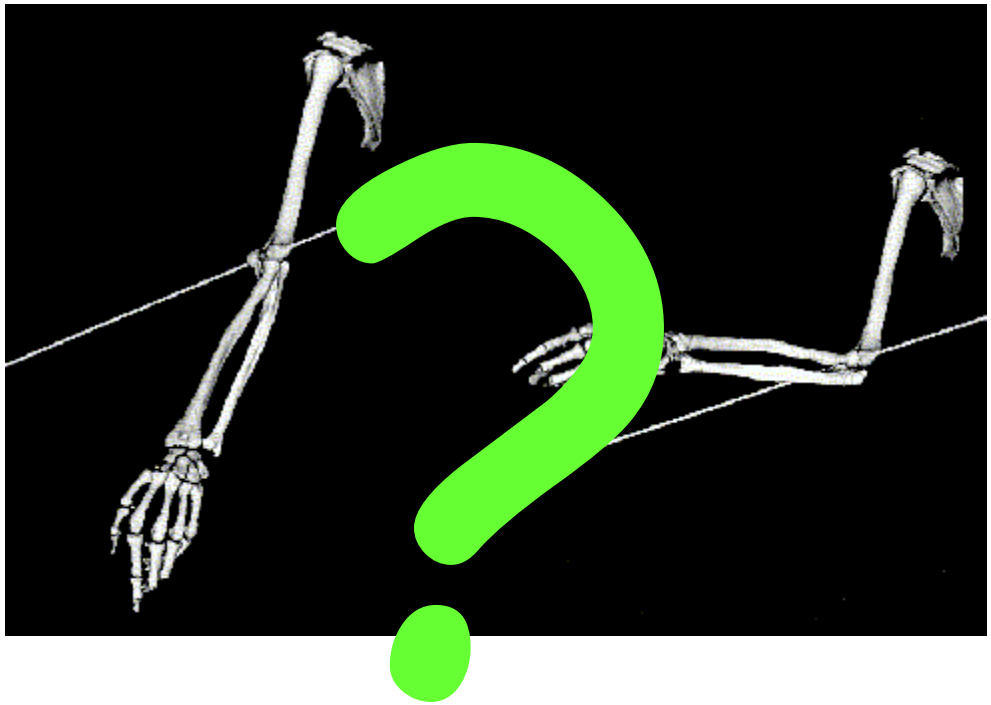
6.(17-16-1)+[10.(1)+6.(2)] =

0 + 10 + 12 = **22 GDLs**

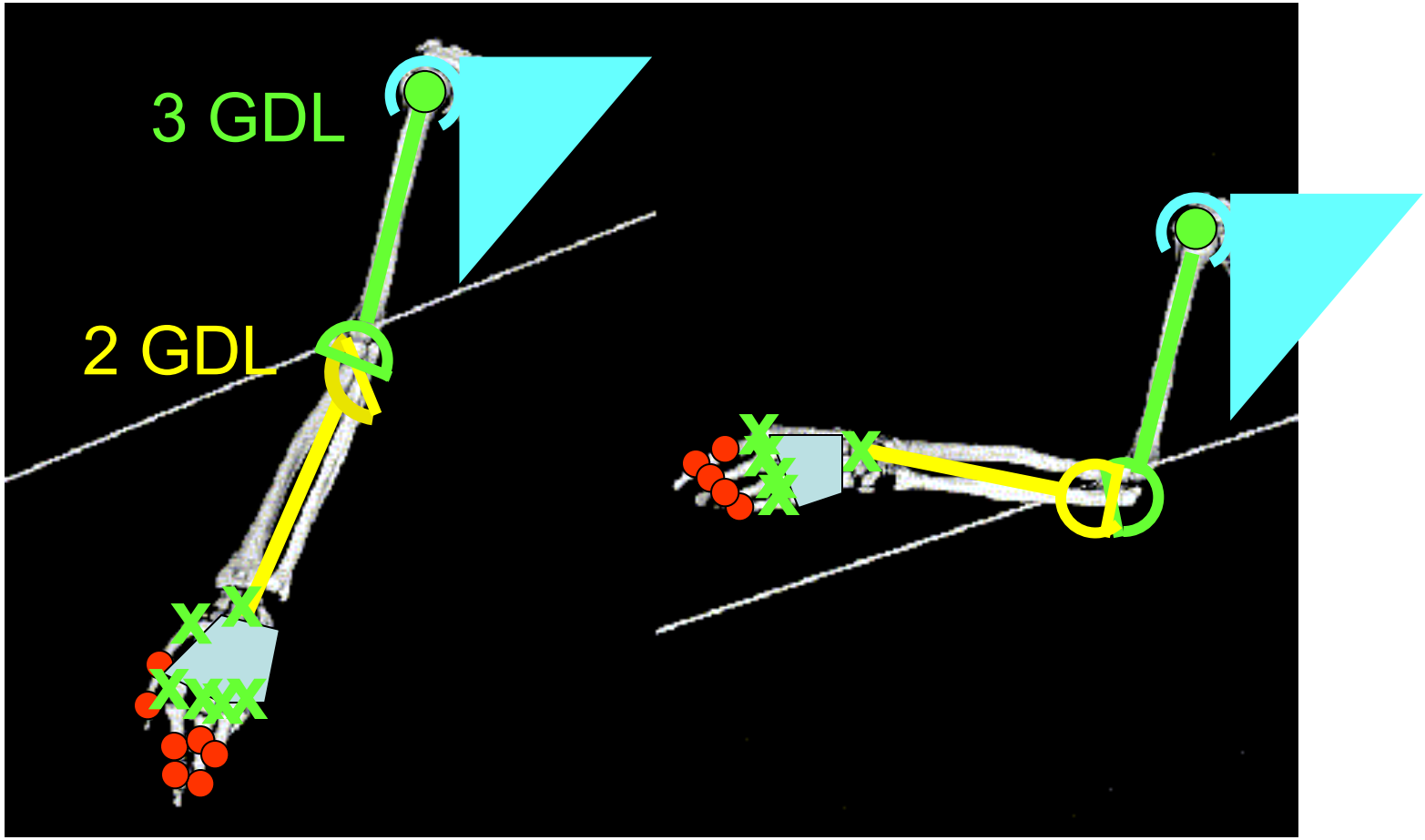
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Cálculo de Graus de Liberdade

E o conjunto braço, ante-braço e mão, quantos GDL's possui?

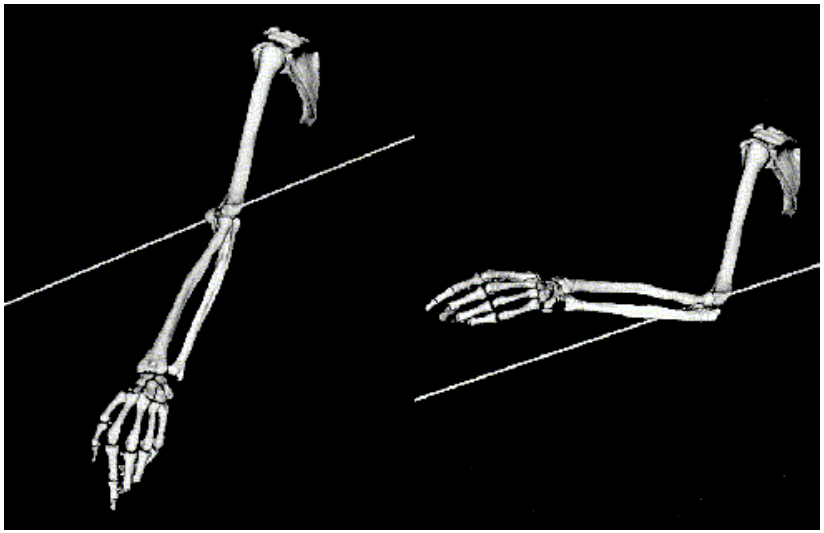


Cálculo de Graus de Liberdade



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Cálculo de Graus de Liberdade



$$M = \lambda(n - n_j - 1) + \sum_{i=1}^{n_j} f_i$$

6.(19-18-1)+[10.(1)+7.(2)+1.(3)] =

0 + 10 + 14 + 3 = **27 GDLs**

No Total: 22 GDLs da mão
3 GDLs do braço
2 GDLs do ante-braço

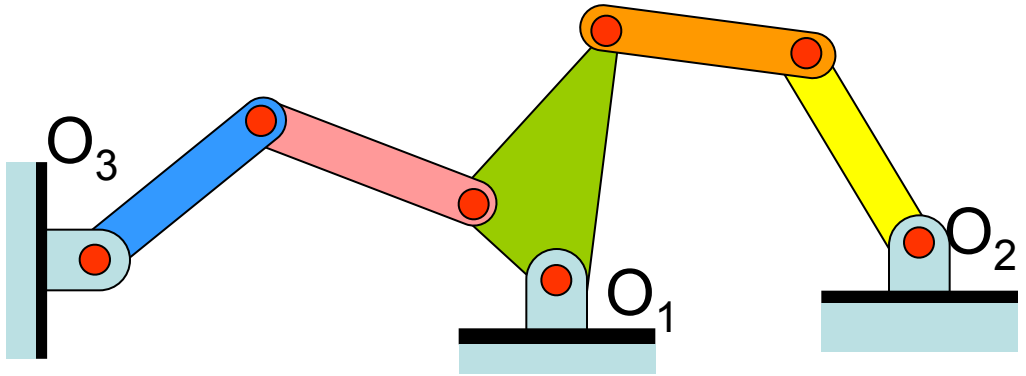
Sumário da Aula

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- **Exercícios Recomendados**
- Bibliografia Recomendada

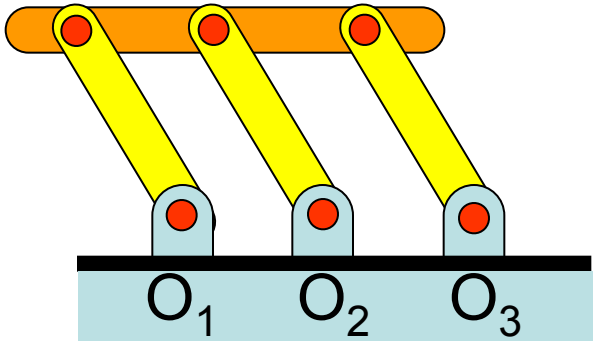
Exercícios Recomendados

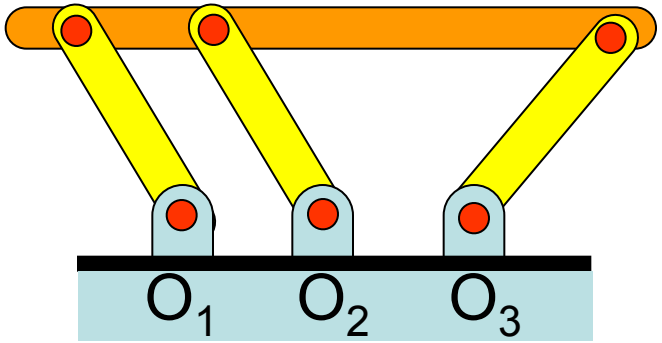
Mecanismos Planares – Observações

(1) Contagem do solo



(2) Existem exceções...



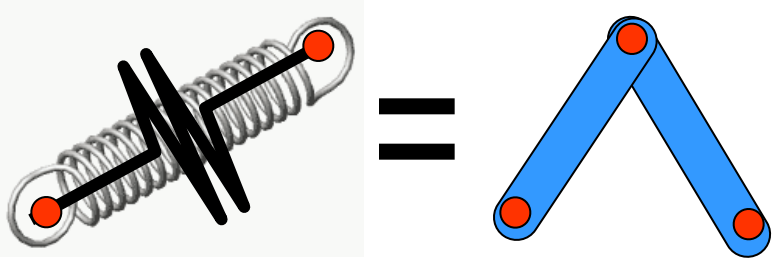


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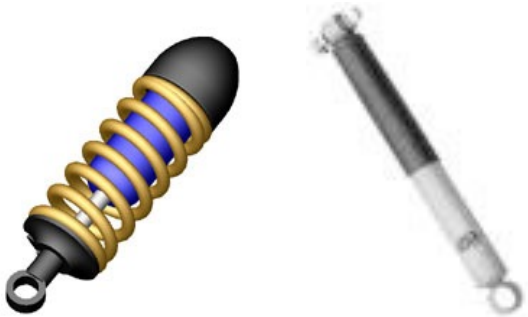
Exercícios Recomendados

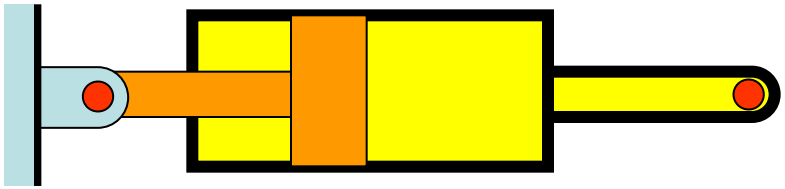
Mecanismos Planares – Observações

(3) Molas



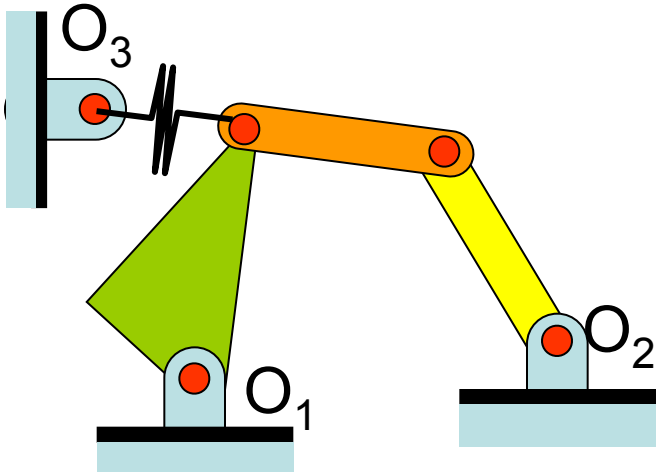
(4) Sistemas Hidráulicos e Pneumáticos

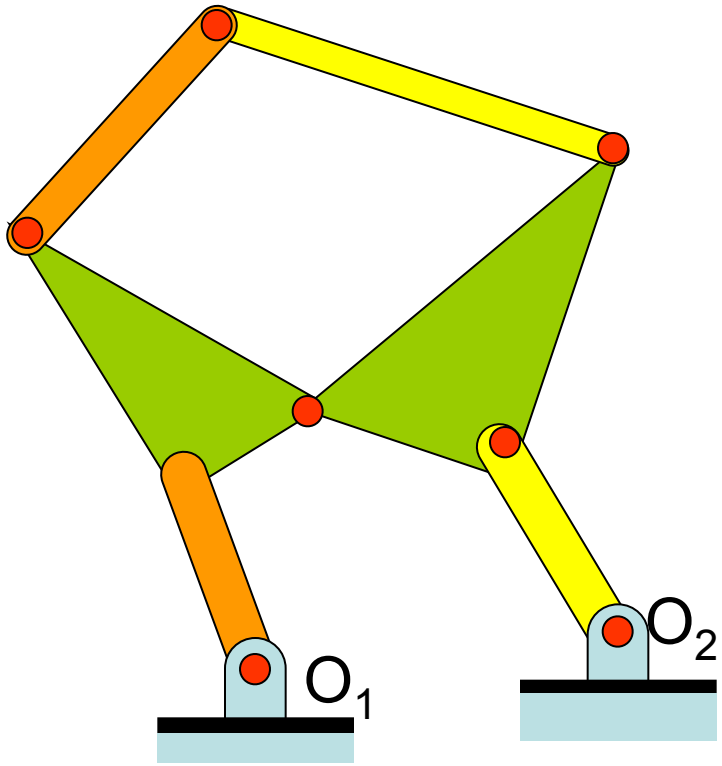




Exercícios Recomendados

Mecanismos Planares

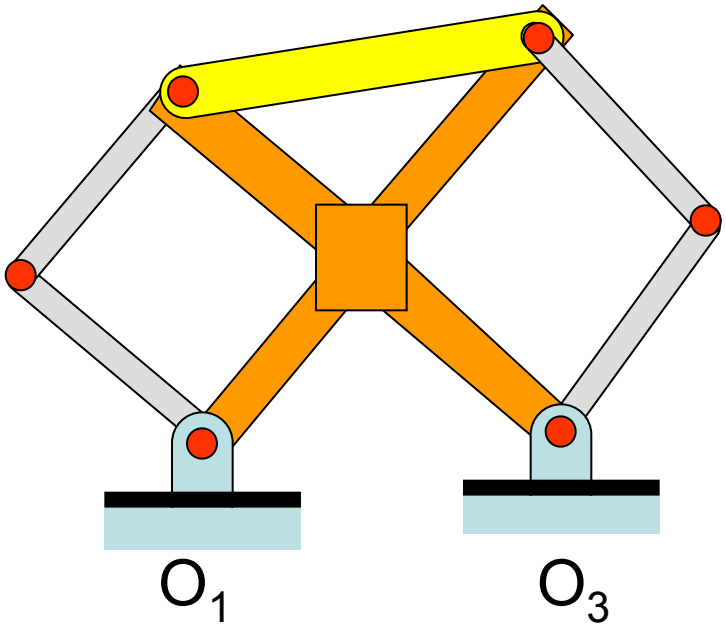


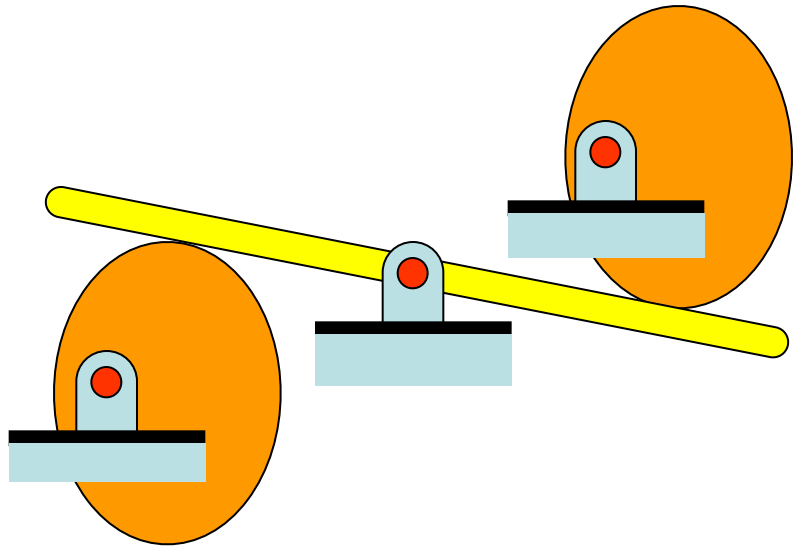


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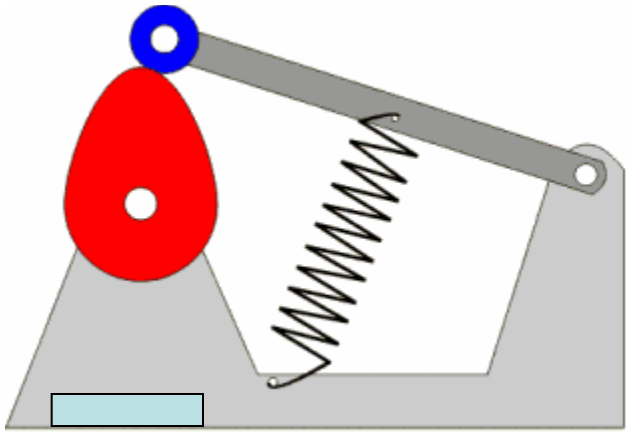
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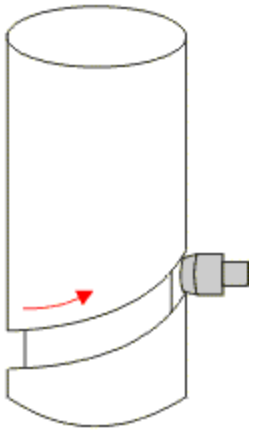


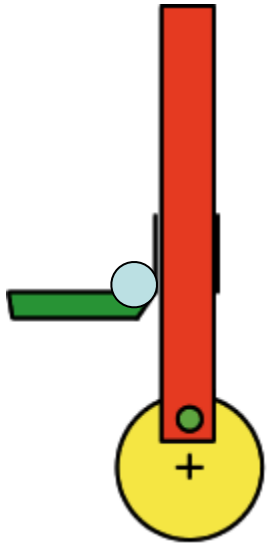
Exercícios Recomendados

Mecanismos Planares



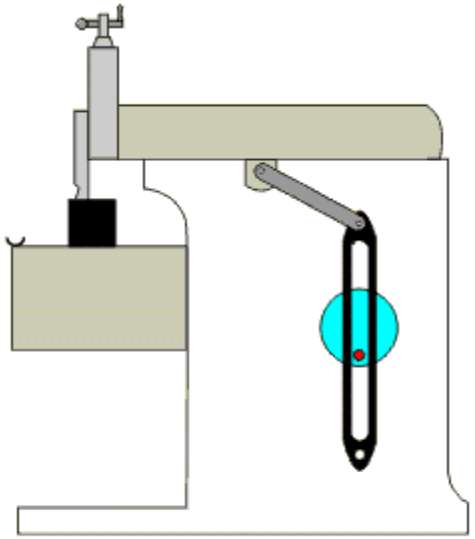




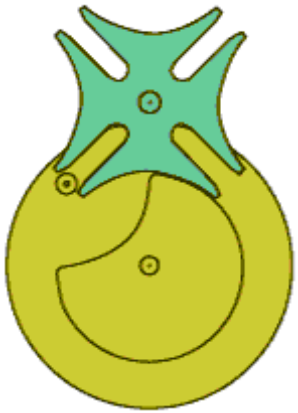


Exercícios Recomendados

Mecanismos Planares



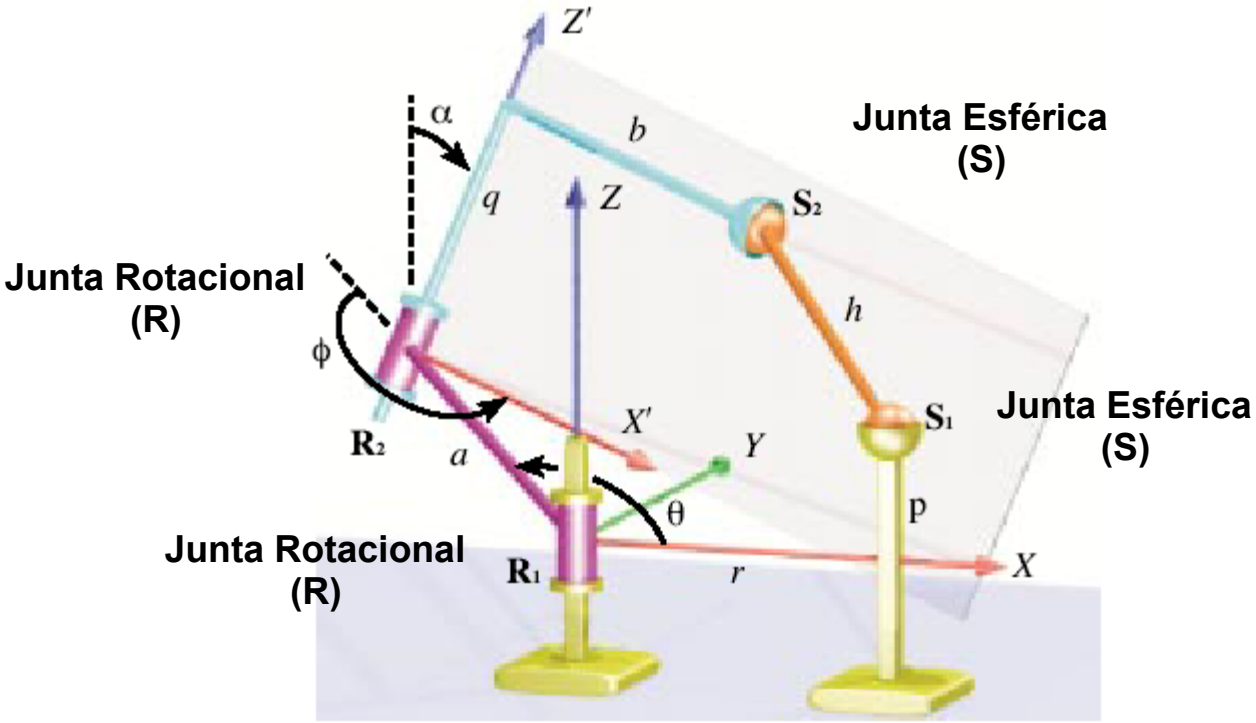




Exercícios Recomendados

Mecanismos Espaciais

- Cuidado com cálculo de GDLs...

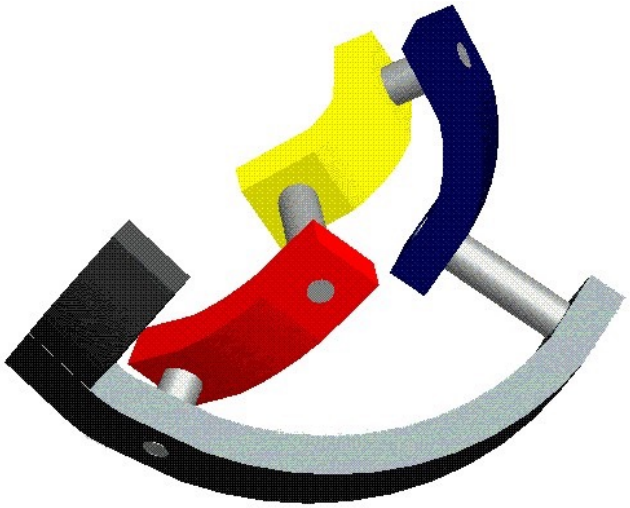


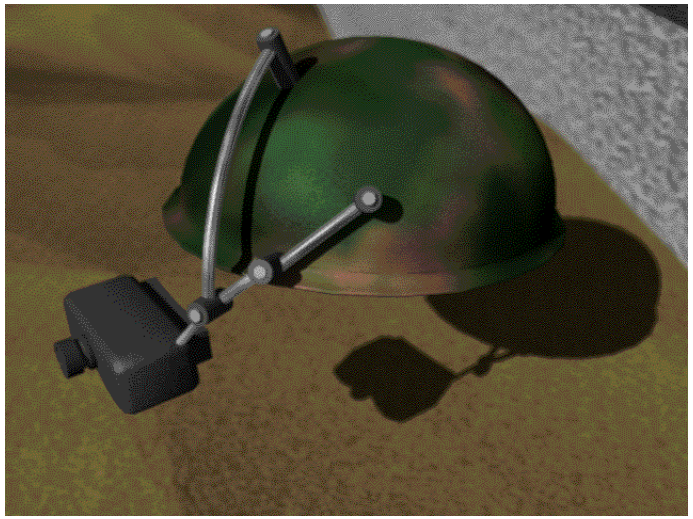
4 barras RRSS

Exercícios Recomendados

Mecanismos Espaciais

4-barras espacial

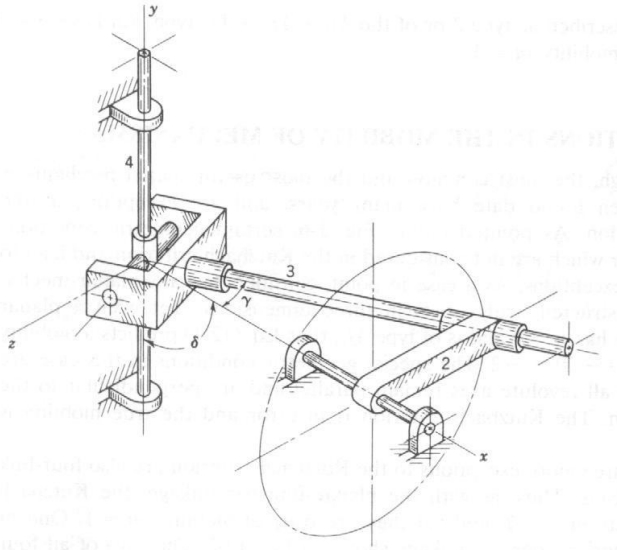




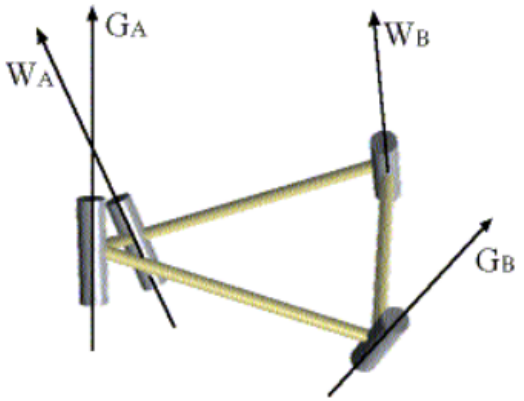
Exercícios Recomendados

Mecanismos Espaciais

- Wobble-Plate (RRRR)



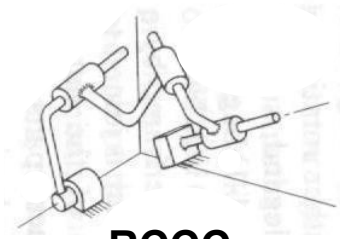
- Mecanismo de Bennett (RRRR)



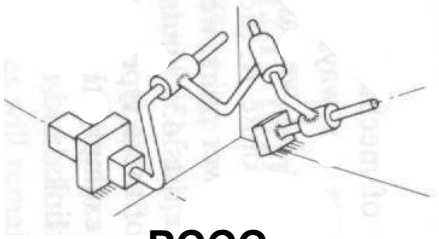
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Exercícios Recomendados

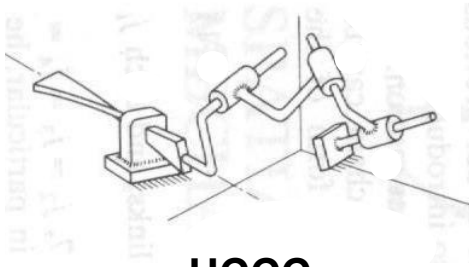
Mecanismos Espaciais



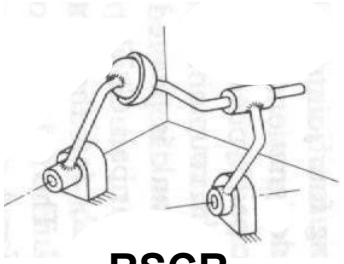
RCCC



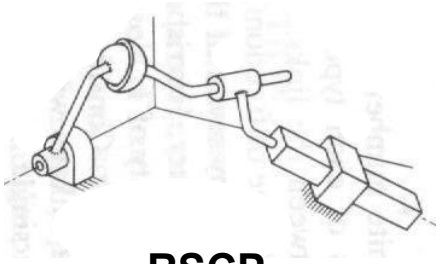
PCCC



HCCC



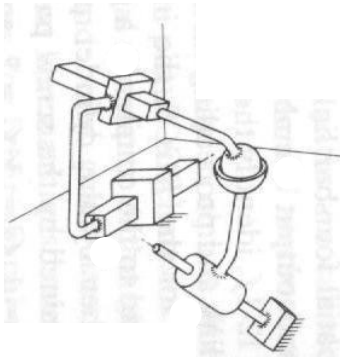
RSCR



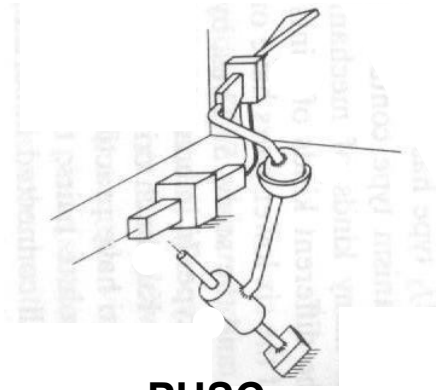
RSCP



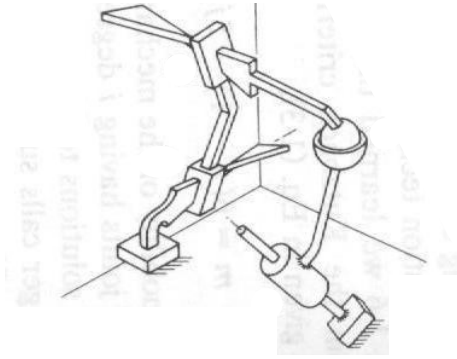
RSCH



PPSC



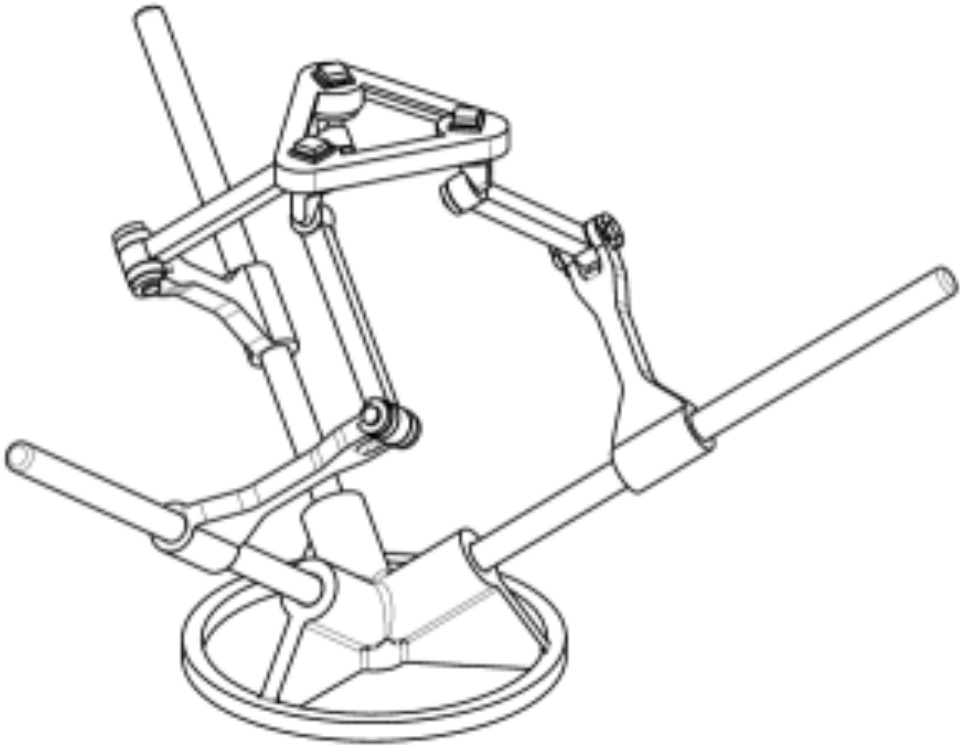
PHSC



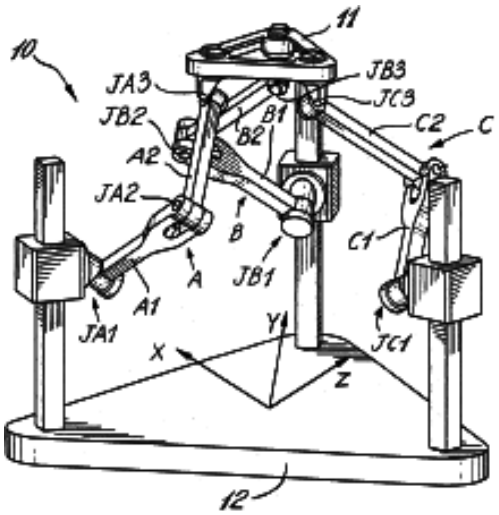
HHSC

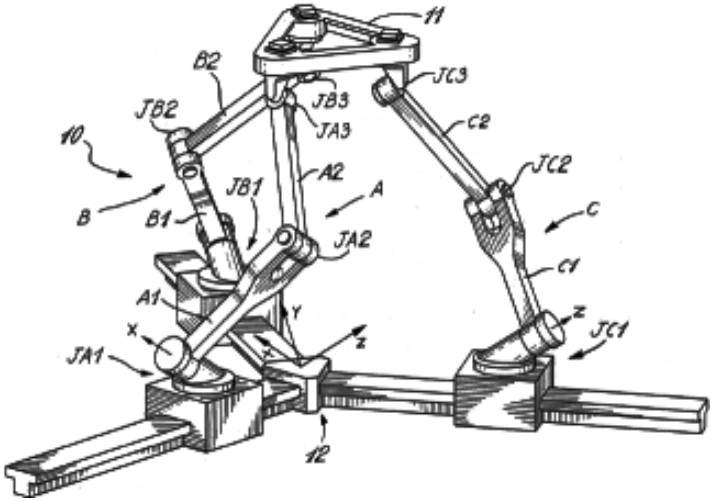
Exercícios Recomendados

Mecanismos Espaciais



Tripteron





US Patent US 6,729,202