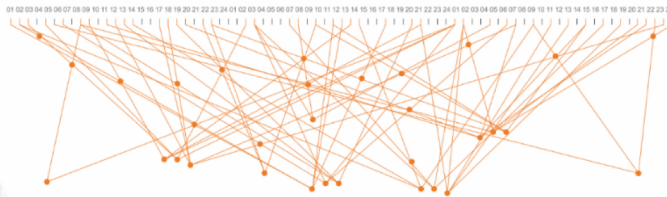


Optimização de turnos de tripulantes

Apresentação ao MAEBD

por Ricardo Saldanha

OPTIMISING
THE RESOURCES
OF THE WORLD



ARRIVÉES

TRAIN	ARRIVING FROM	TIME
36	OTTAWA	17:56
69	NEW YORK	19:10
8	OTTAWA	19:56
	TORONTO	20:16
	REC	20:51
		21:4

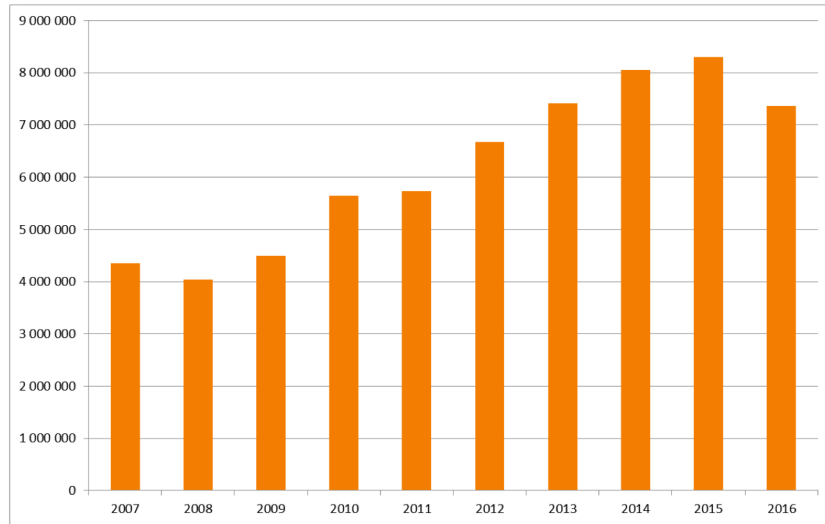
Quem somos

- A **SISCOG** é uma empresa de desenvolvimento de software, fundada em **1986**, a trabalhar no domínio ferroviário desde 1988
- Especializada em **planeamento e gestão de recursos**
(horários, veículos e pessoal)
 - **Produtos**
 - Sistemas baseados em produtos
- Forte capacidade de **optimização**
- Utiliza técnicas de **Inteligência Artificial** e **Investigação Operacional**
- Ajuda operadores **ferroviários** e **metros** em todo o mundo



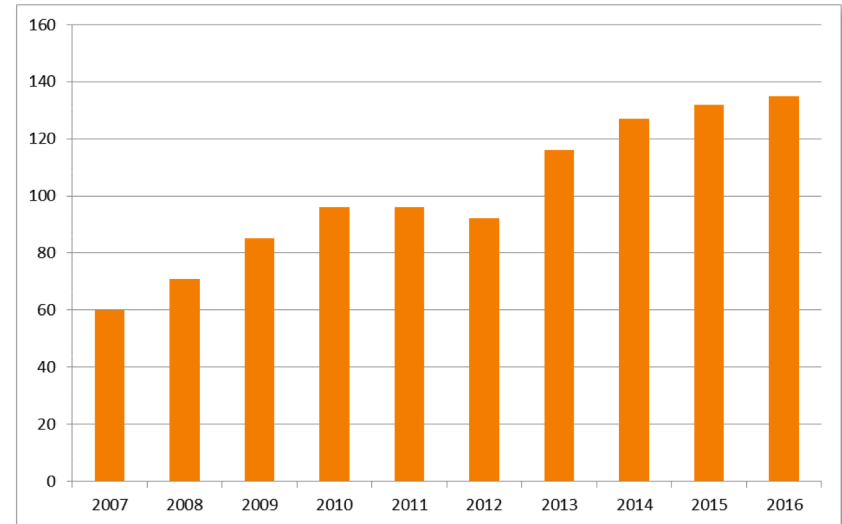
Sustentabilidade

Vendas (€)



- **Solidez financeira**
- **Clientes fidelizados**, que continuam a comprar mais módulos além dos inicialmente contratados

Equipa (nr.)



- **90% com licenciatura** em Matemática, Engenharia e Tecnologias de Informação
- **7 PhDs** e **47 Mestres**

Prémios de Recursos Humanos

Melhor Empresa para Trabalhar

2017-2011

**Exame/Accenture/
Everis/AESE**

2014, 2011 e 2010

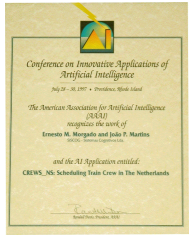
**Great Place To Work
Institute**



Qualidade & Inovação e Sustentabilidade no centro de tudo o que fazemos

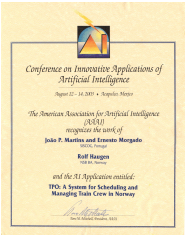
2015

“Best Practice Paper Award” na
CASPT, Conference on Advanced Systems in Public Transport



2012, 2003 and 1997

Innovative Application Award pela
AAAI - Association for the Advancement of Artificial Intelligence



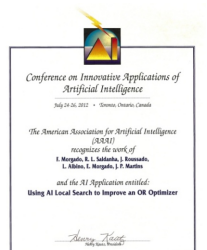
2010

Menção Honrosa pela
“Innovation Awards COTEC-Unicer”



2006

Medalha de Mérito pelo
“ComputerWorld Honors program”



Os nossos Clientes



Metro de Londres



Caminhos-de-Ferro do Canadá



Metro de Lisboa



Comboios Suburbanos
de Copenhaga



Caminhos-de-Ferro da Dinamarca



Caminhos-de-Ferro da Holanda



Comboios Suburbanos da
Catalunha



Caminhos-de-Ferro da Finlândia



Caminhos-de-Ferro da Noruega



C. Ferro Ibéricos (mercadorias)

*O sistema mais antigo está em operação
contínua desde 1998*



Caminhos-de-ferro Holandeses (NS)

- **Sobre**

- Transporta mais de 1.200.000 passageiros / dia
- 4.700 comboios / dia
- Pessoal planeado: **mais de 5.200** (maquinistas e revisores)
- Sistema em operação **desde 1998**

- **Benefícios**

- **6% de redução** de tripulantes
- **60% de redução** de planeadores
- **Redução no tempo de planeamento** - alguns dias vs. vários meses
- Apenas **15-20 minutos** para reagir a incidentes
- Turnos bastante **“sociais”**
 - Tempos de trabalho médios e desvios
 - **Trabalho não repetitivo**
 - Distribuição de **“bons e maus turnos”** entre bases de pessoal

Oferta de soluções para resolver o desafio da produtividade



ONTIME

**Criação &
Gestão de
Horários**



FLEET

**Planeamento &
Gestão de
Veículos**



CREWS

**Planeamento &
Gestão de
Pessoal**

Interesse da SISCOG em *Big Data*

- Tecnologias estratégicas
 - *Machine learning / Big Data*
 - Robótica
- Parcerias com universidades e institutos
- Possíveis aplicações (transportes)
 - Optimização (desafio)
 - Outros...

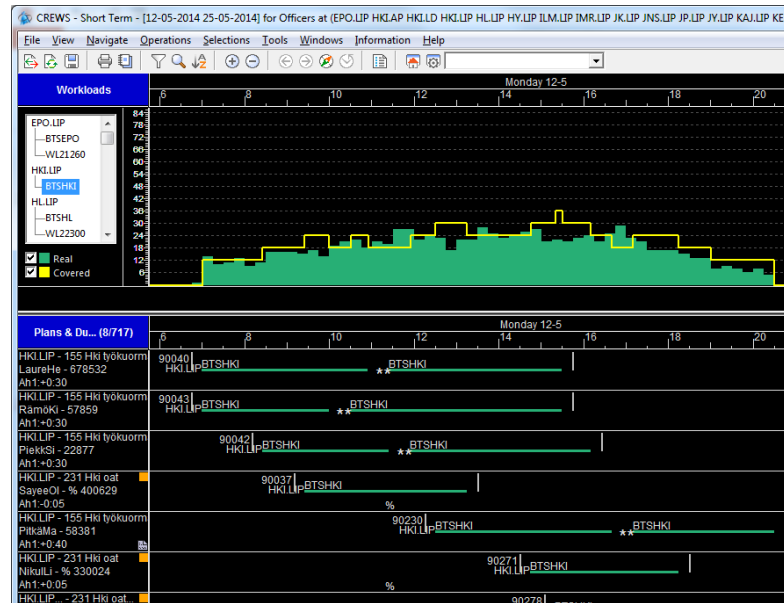
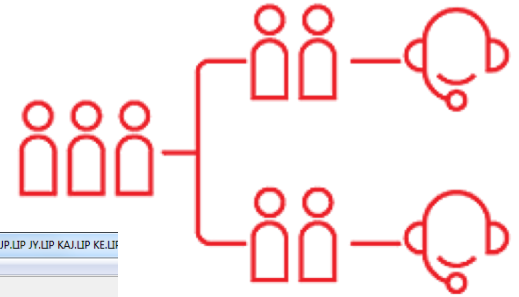
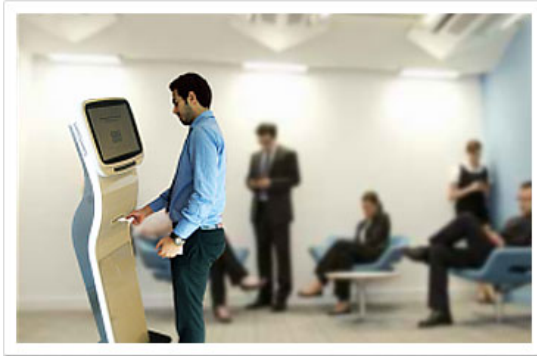
Previsão de indisponibilidade de recursos

- Objectivo: planeamento de férias e de reservas optimizado
- Dados: histórico de avarias e absentismo



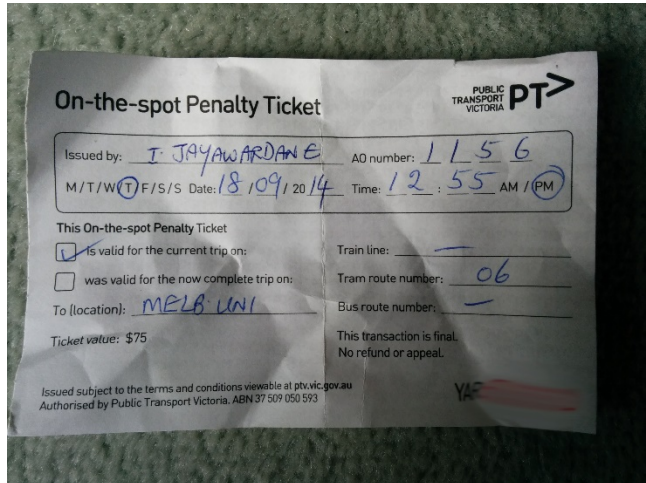
Previsão das necessidades de pessoal

- Objectivo: ajustar capacidade disponível às necessidades
- Dados: histórico de senhas de atendimento / chamadas



Previsão de risco de falha de segurança

- Objectivo: patrulhamento mais eficaz
- Dados: histórico de multas, queixas e registo de incidentes





Desafio (exemplo)

C. Tarefas = 4

C. Turnos = 19

Total (CT) = 23

17
A B

Rui Silva

1 3 ★ 8 11
A B B A A B B A

Pedro Santos

2 6 ★ 10 14
A B B A A B B A

Miguel Ferreira

4 7 ★ 13 15
A B B A A B B A

José Rodrigues

6 5 ★ 9 12
B A A B B A A B

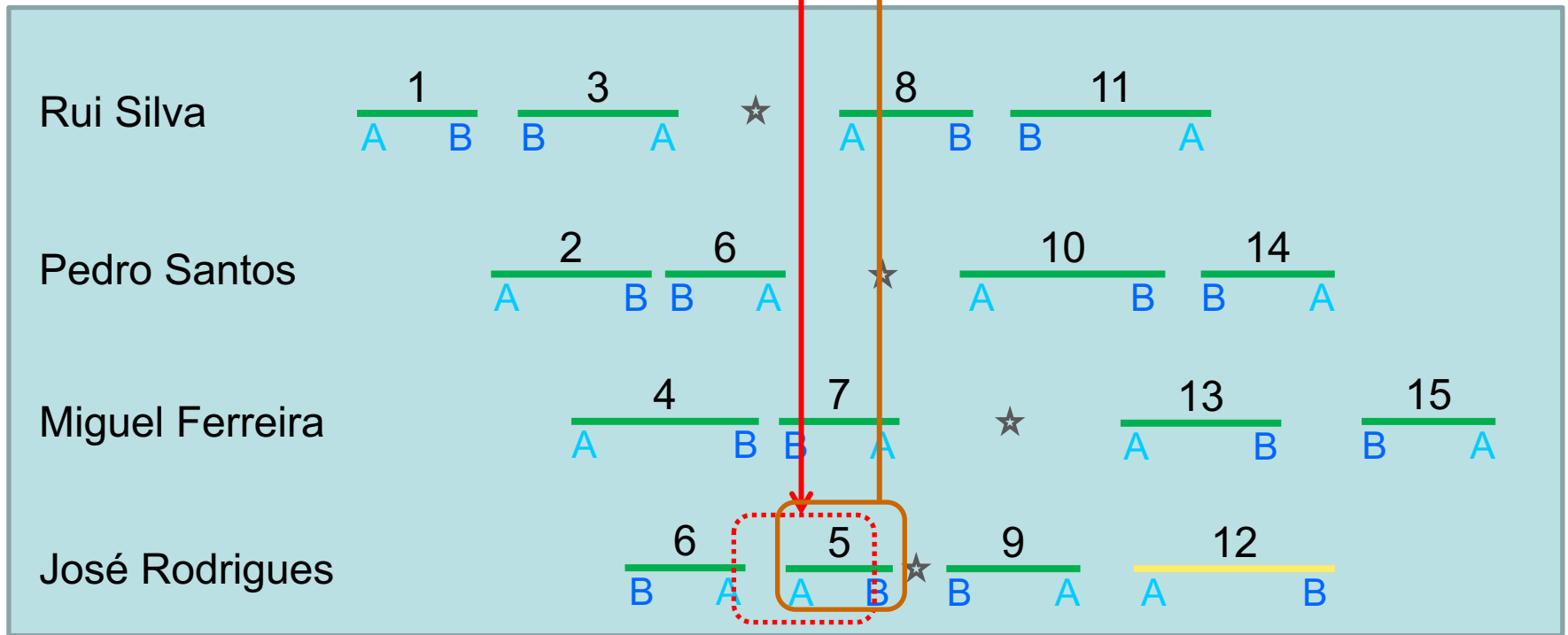


Desafio (exemplo)

C. Tarefas = 4

C. Turnos = 19

Total (CT) = 23



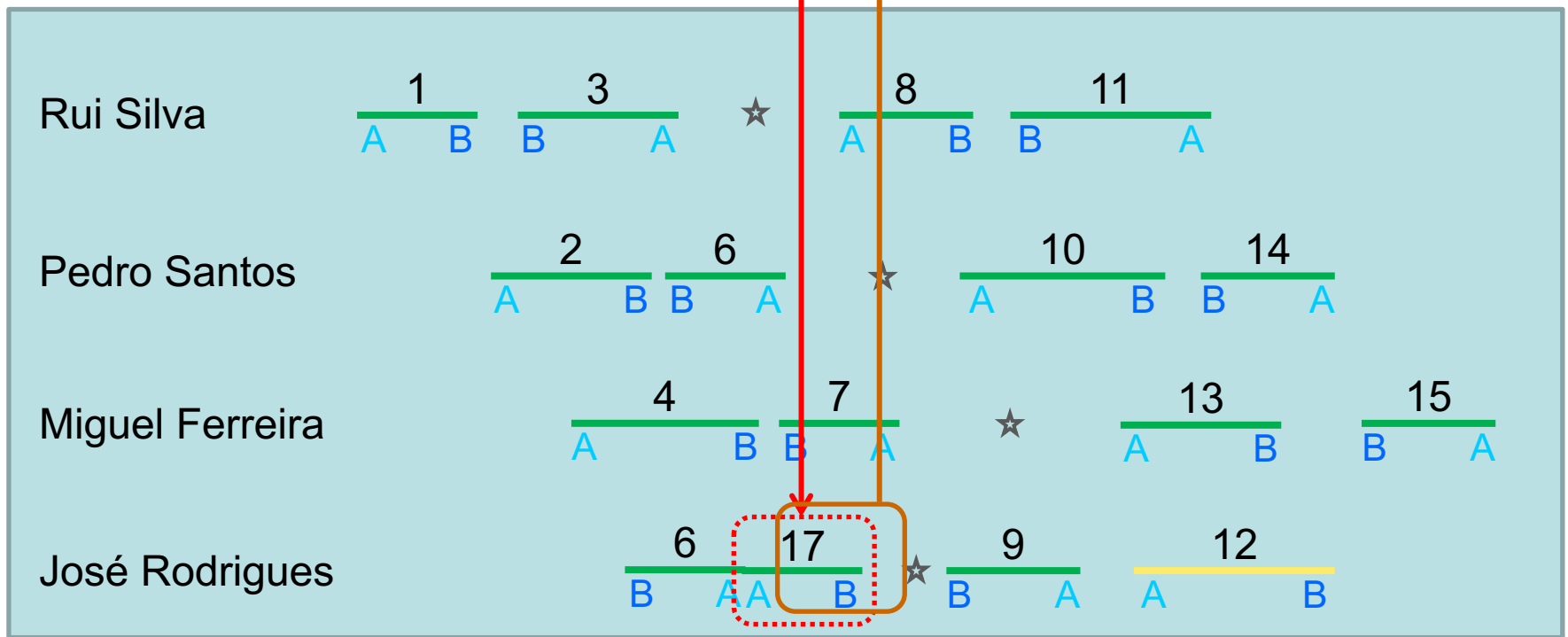


Desafio (exemplo)

C. Tarefas = 4

C. Turnos = 19

Total (CT) = 23





Desafio (exemplo)

C. Tarefas = 4

C. Turnos = 19

Total (CT) = 23

5
A B

Rui Silva

1 3 8 11
A B B A A B B A

★

Pedro Santos

2 6 10 14
A B B A A B B A

★

Miguel Ferreira

4 7 13 15
A B B A A B B A

★

José Rodrigues

6 17 9 12
B A A B B A A B

★



Desafio (exemplo)

C. Tarefas = 4

C. Turnos = 19

Total (CT) = 23



Rui Silva



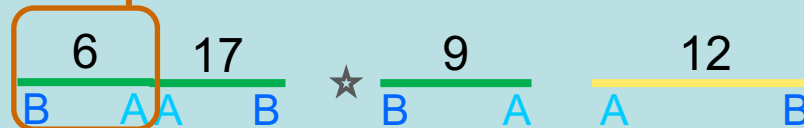
Pedro Santos

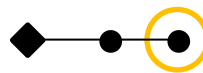


Miguel Ferreira



José Rodrigues



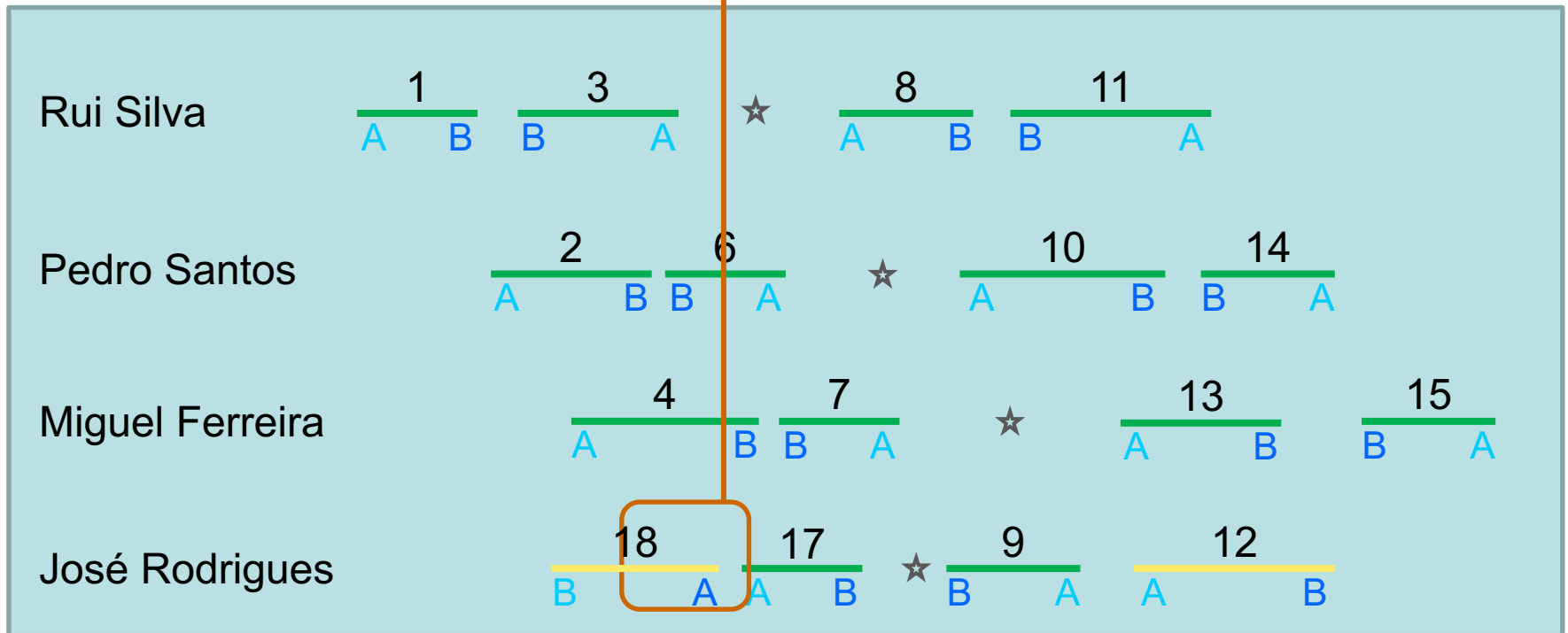


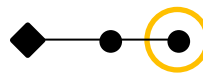
Desafio (exemplo)

C. Tarefas = 8 (+4)

C. Turnos = 20 (+1)

Total (CT) = 28 (+5)





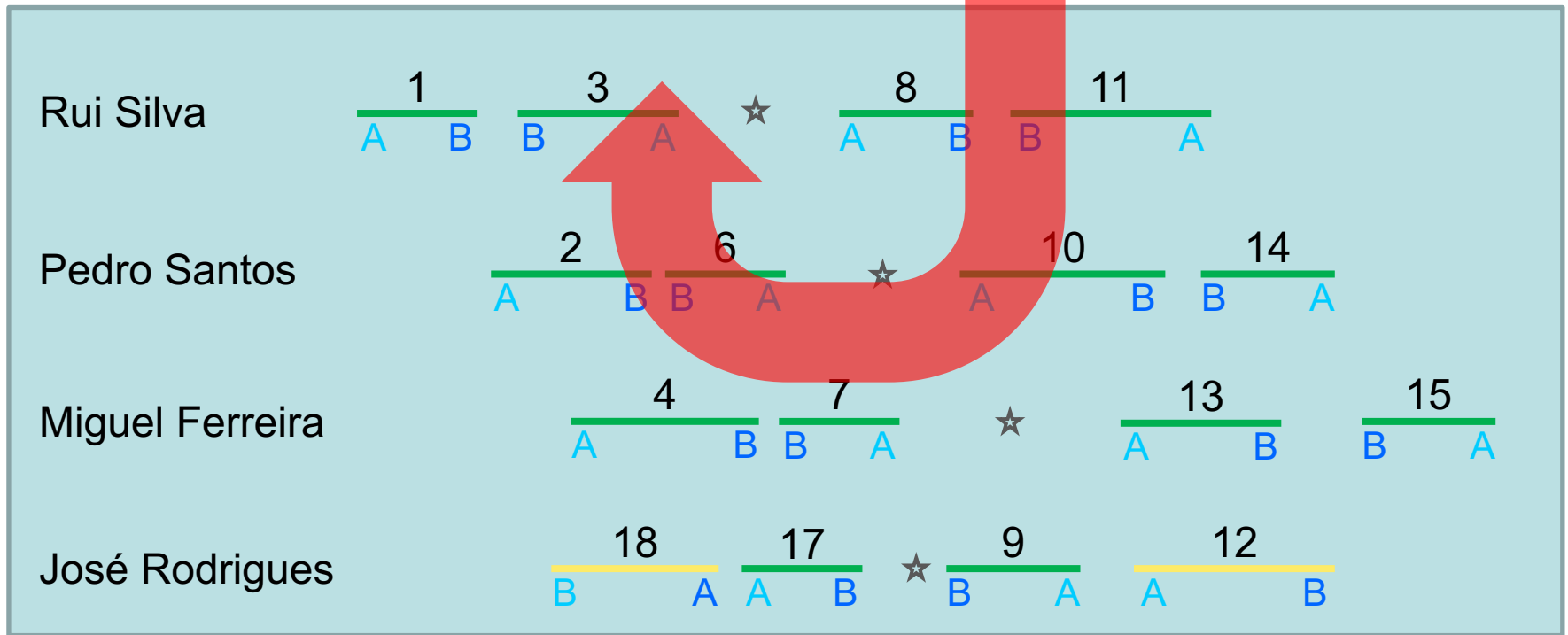
Desafio (exemplo)

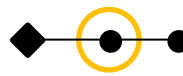
C. Tarefas = 8 (+4)

C. Turnos = 20 (+1)

Total (CT) = 28 (+5)

6 5
B A A B





Desafio (exemplo)

C. Tarefas = 4

C. Turnos = 19

Total (CT) = 23

5
A B

Rui Silva

1 3 8 11
A B B A A B B A

★

Pedro Santos

2 6 10 14
A B B A A B B A

★

Miguel Ferreira

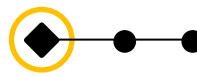
4 7 13 15
A B B A A B B A

★

José Rodrigues

6 17 9 12
B A A B B A A B

★



Desafio (exemplo)

C. Tarefas = 4

C. Turnos = 19

Total (CT) = 23

17
A B

Rui Silva

1 3 8 11
A B B A A B B A

★

Pedro Santos

2 6 10 14
A B B A A B B A

★

Miguel Ferreira

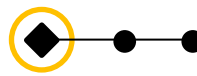
4 7 13 15
A B B A A B B A

★

José Rodrigues

6 5 9 12
B A A B B A A B

★

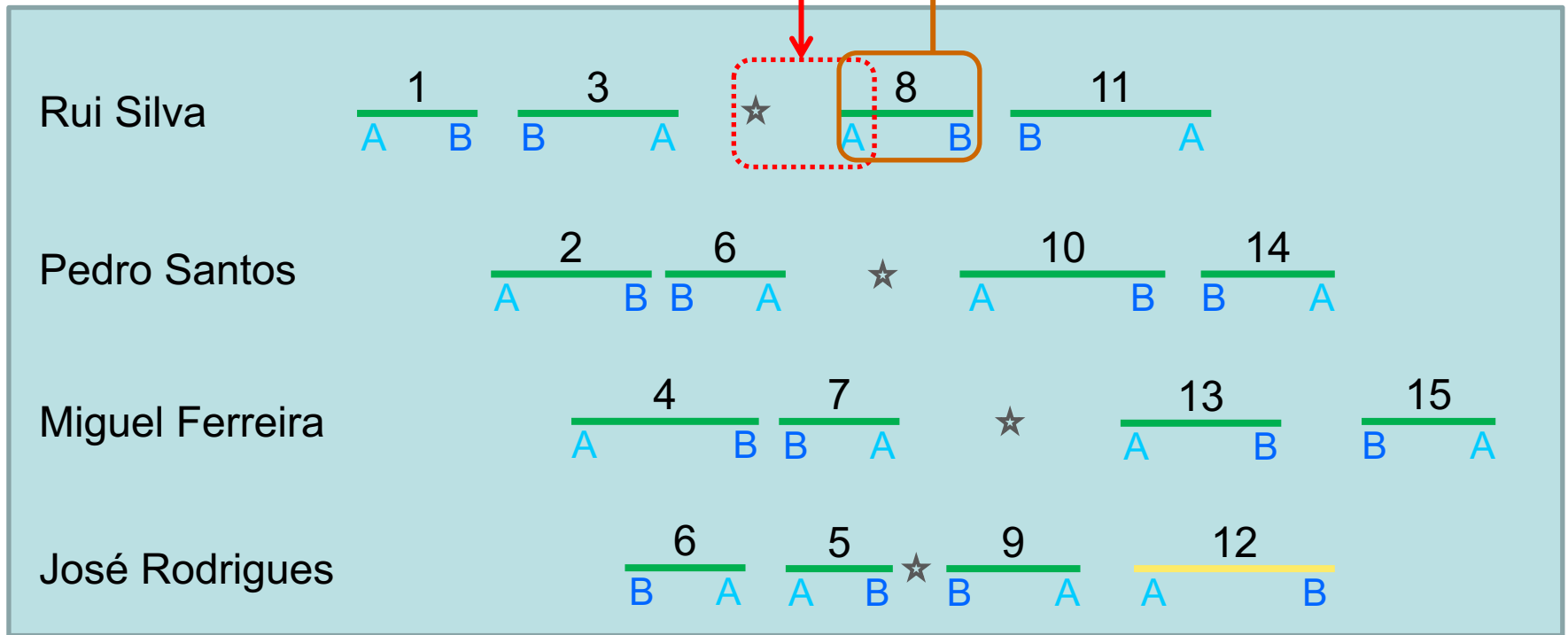


Desafio (exemplo)

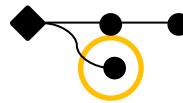
C. Tarefas = 4

C. Turnos = 19

Total (CT) = 23



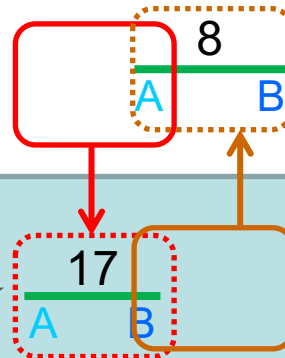
Desafio (exemplo)



C. Tarefas = 4

C. Turnos = 19

Total (CT) = 23



Rui Silva



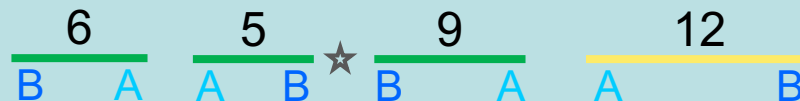
Pedro Santos



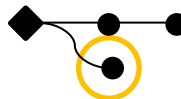
Miguel Ferreira



José Rodrigues



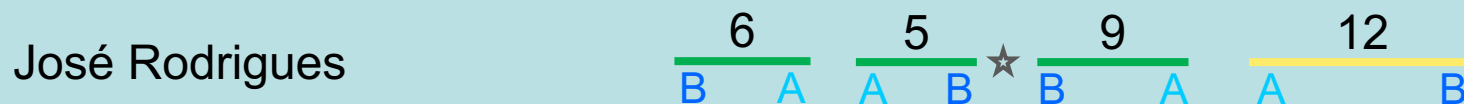
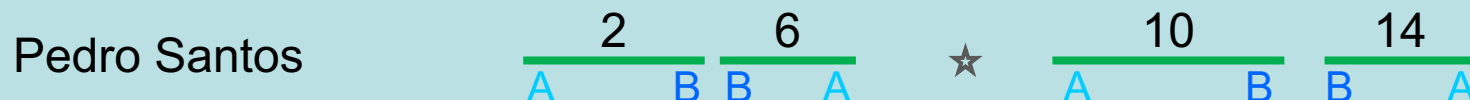
Desafio (exemplo)



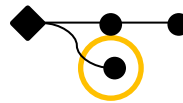
C. Tarefas = 4

C. Turnos = 19

Total (CT) = 23



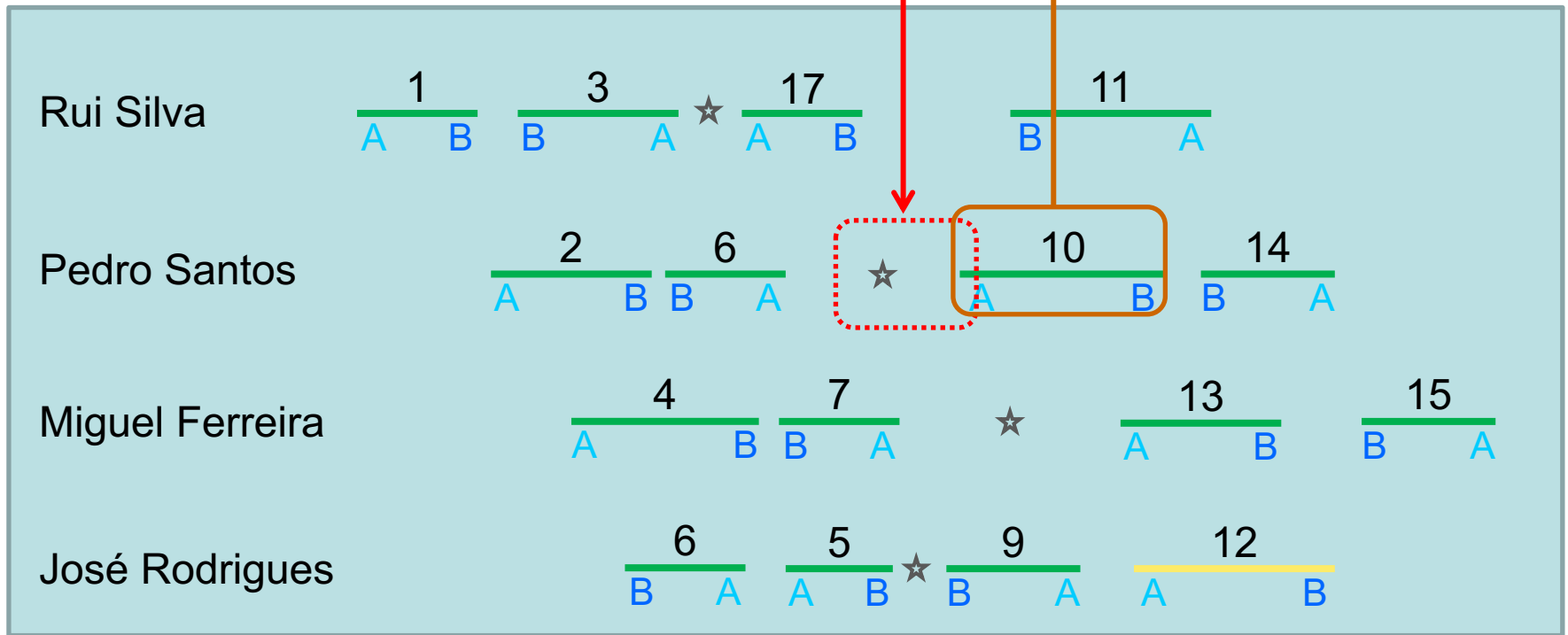
Desafio (exemplo)



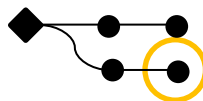
C. Tarefas = 4

C. Turnos = 19

Total (CT) = 23



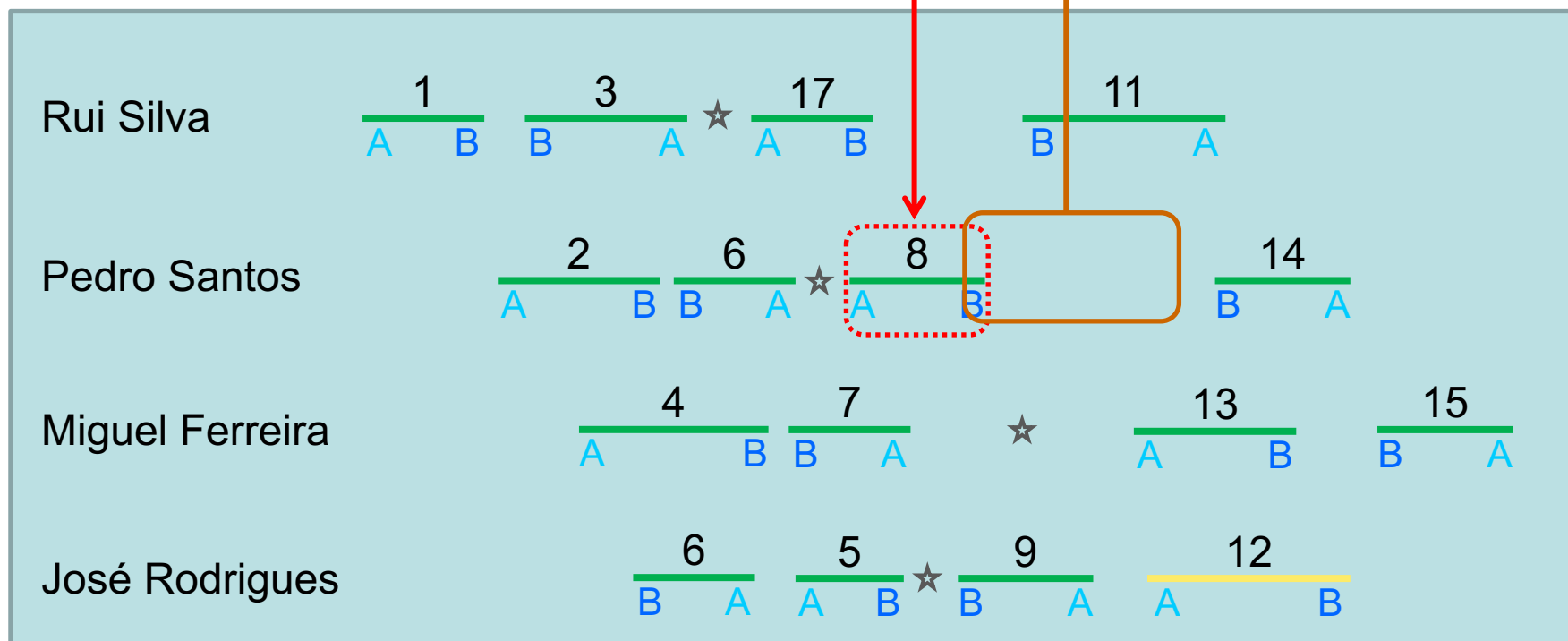
Desafio (exemplo)



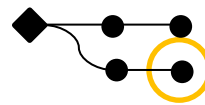
C. Tarefas = 4

C. Turnos = 19

Total (CT) = 23



Desafio (exemplo)



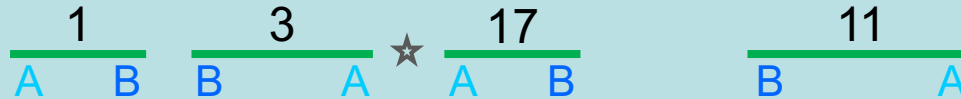
C. Tarefas = 4

C. Turnos = 19

Total (CT) = 23



Rui Silva



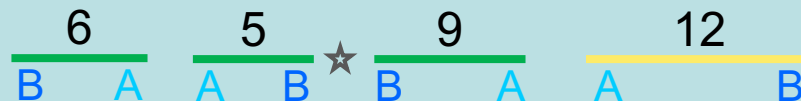
Pedro Santos



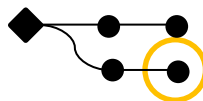
Miguel Ferreira



José Rodrigues



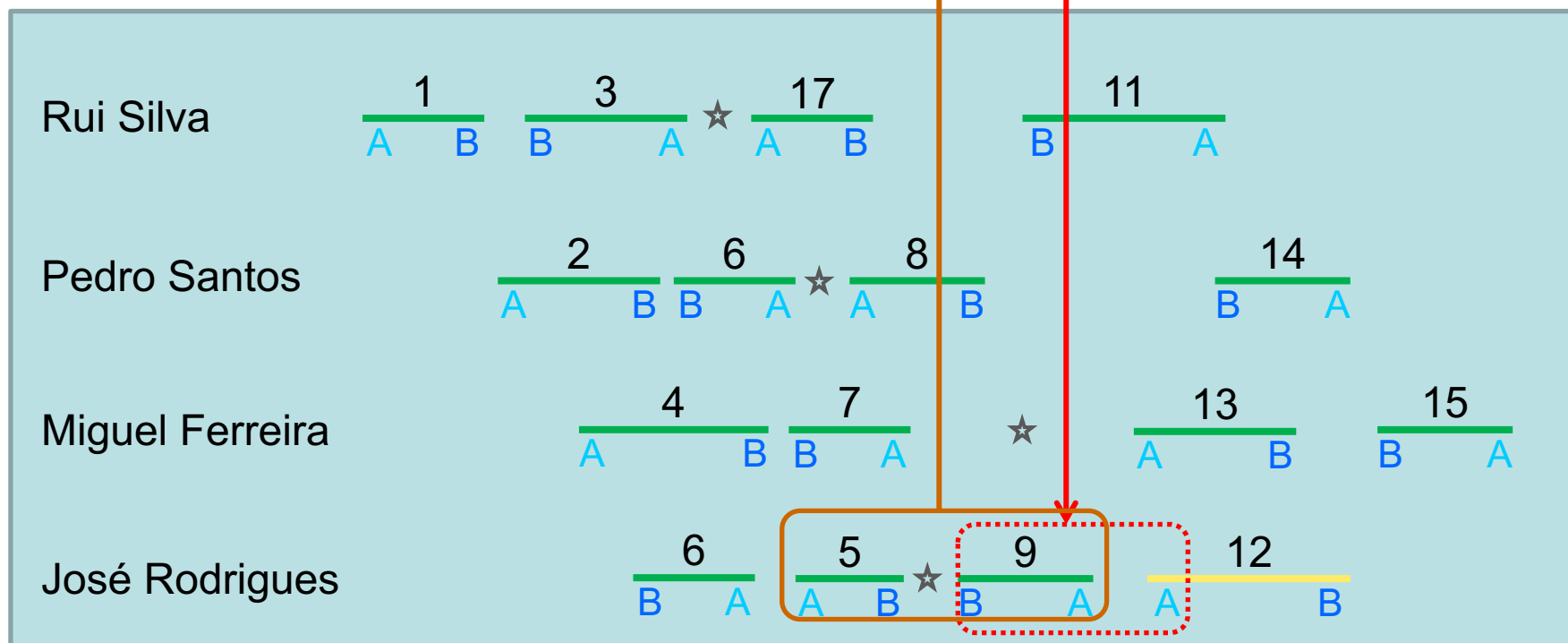
Desafio (exemplo)



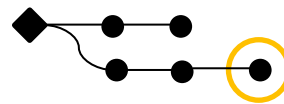
C. Tarefas = 4

C. Turnos = 19

Total (CT) = 23



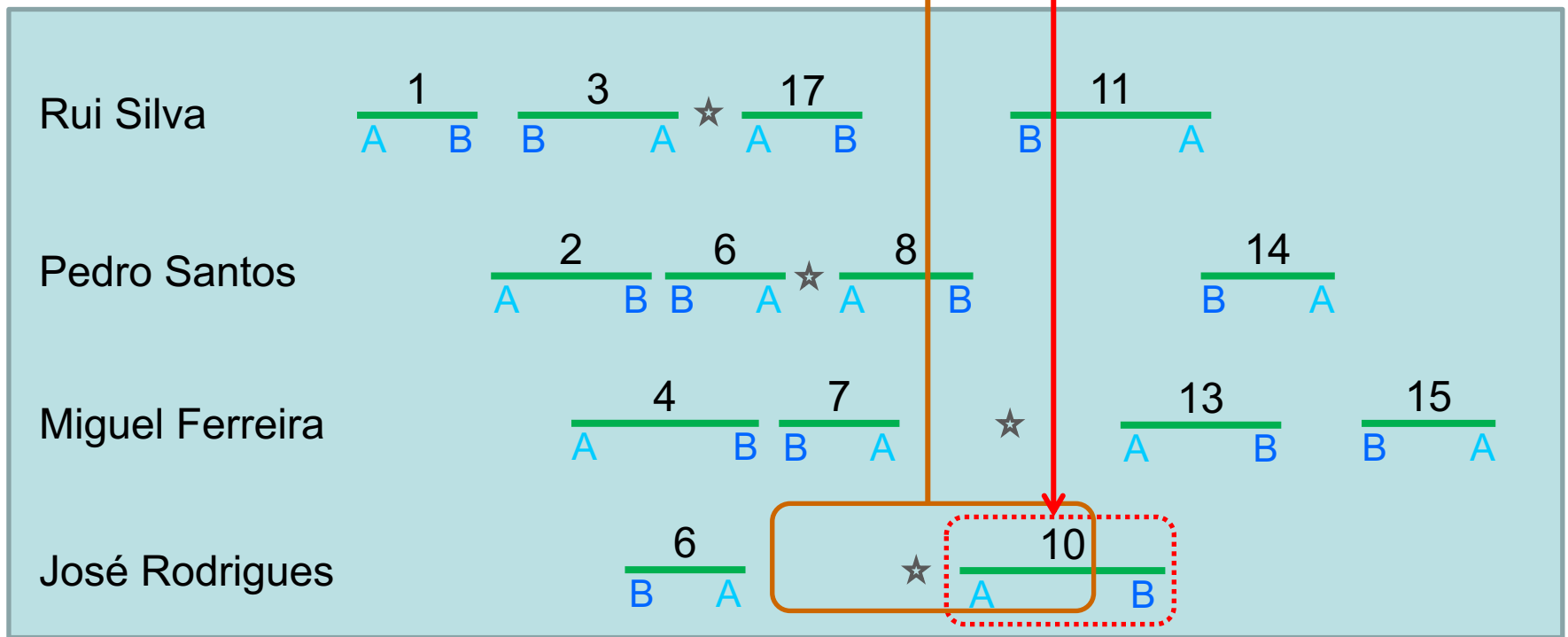
Desafio (exemplo)



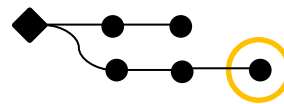
C. Tarefas = 8 (+4)

C. Turnos = 18 (-1)

Total (CT) = 26 (+3)



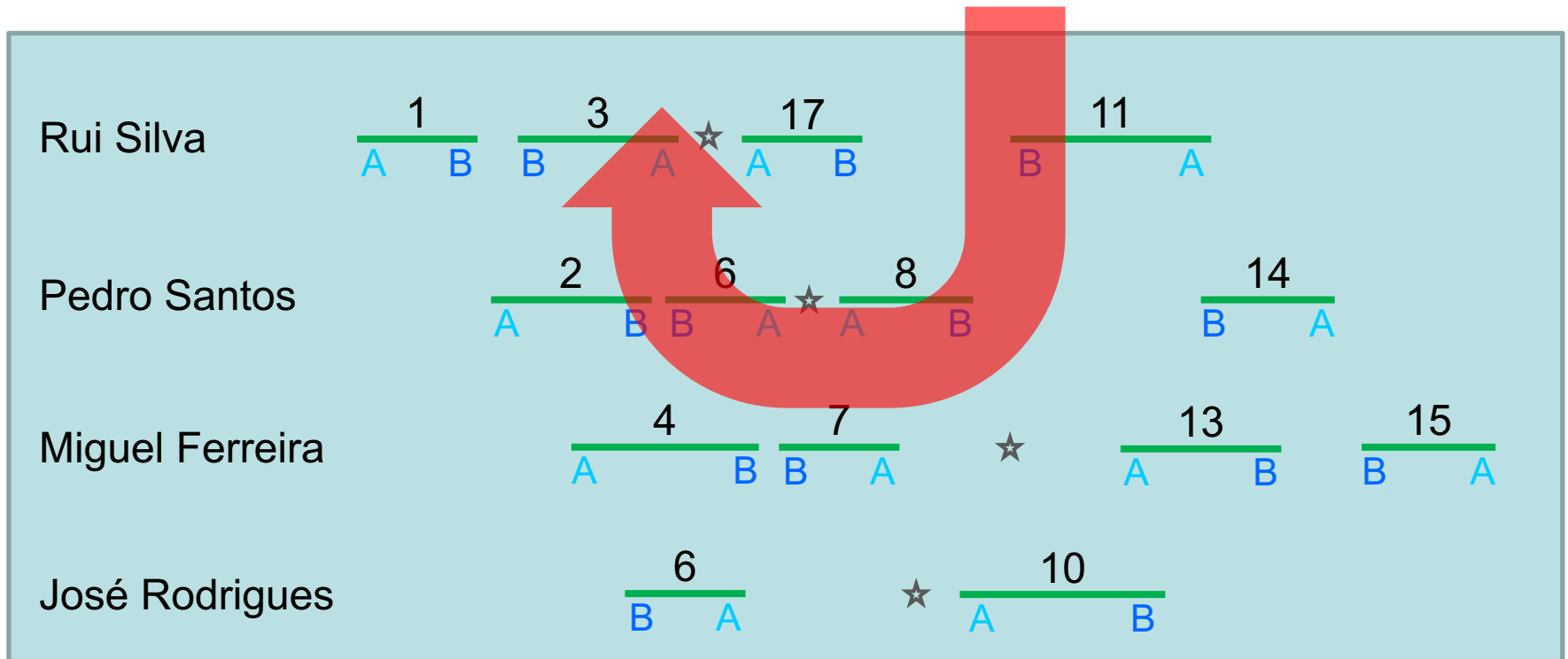
Desafio (exemplo)



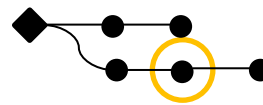
C. Tarefas = 8 (+4)

C. Turnos = 18 (-1)

Total (CT) = 26 (+3)



Desafio (exemplo)



C. Tarefas = 4

C. Turnos = 19

Total (CT) = 23



Rui Silva



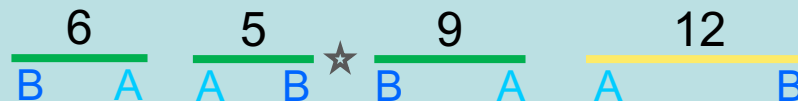
Pedro Santos



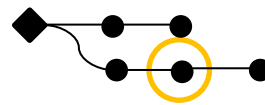
Miguel Ferreira



José Rodrigues



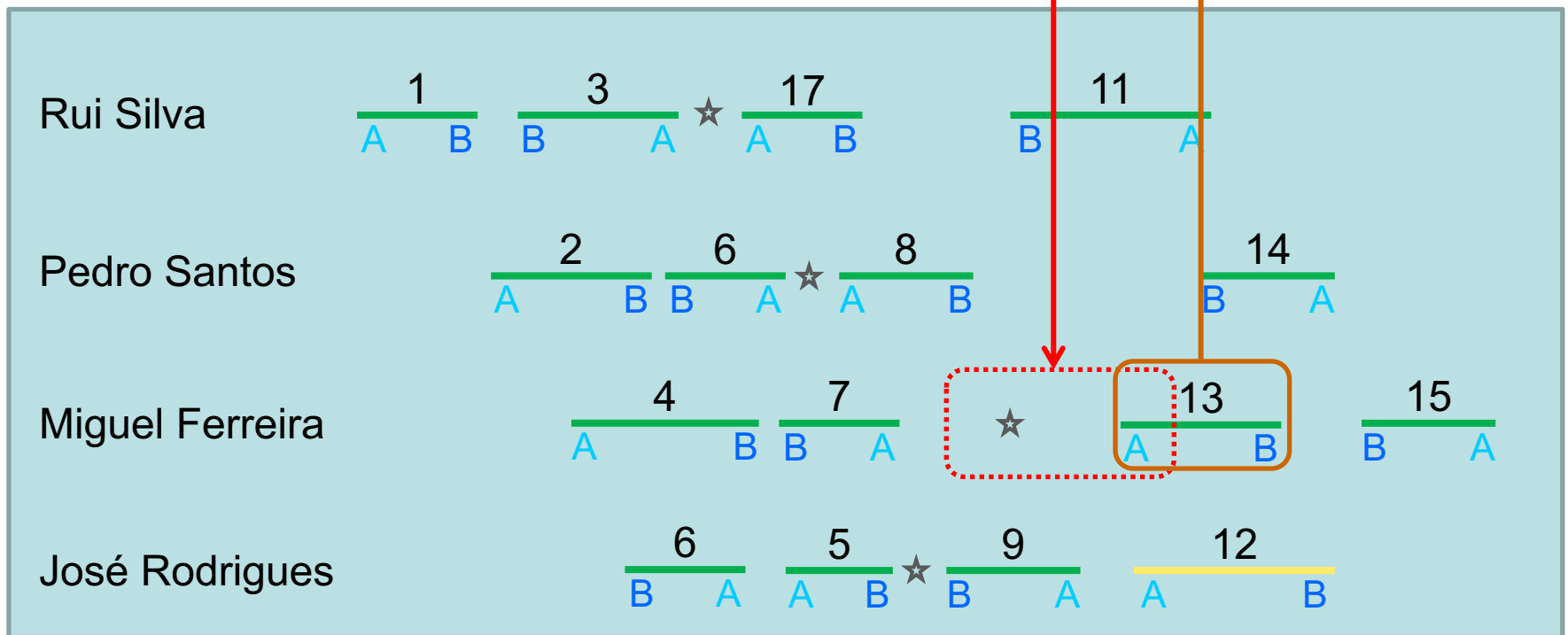
Desafio (exemplo)



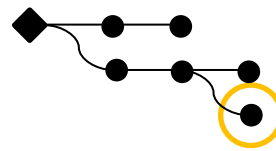
C. Tarefas = 4

C. Turnos = 19

Total (CT) = 23



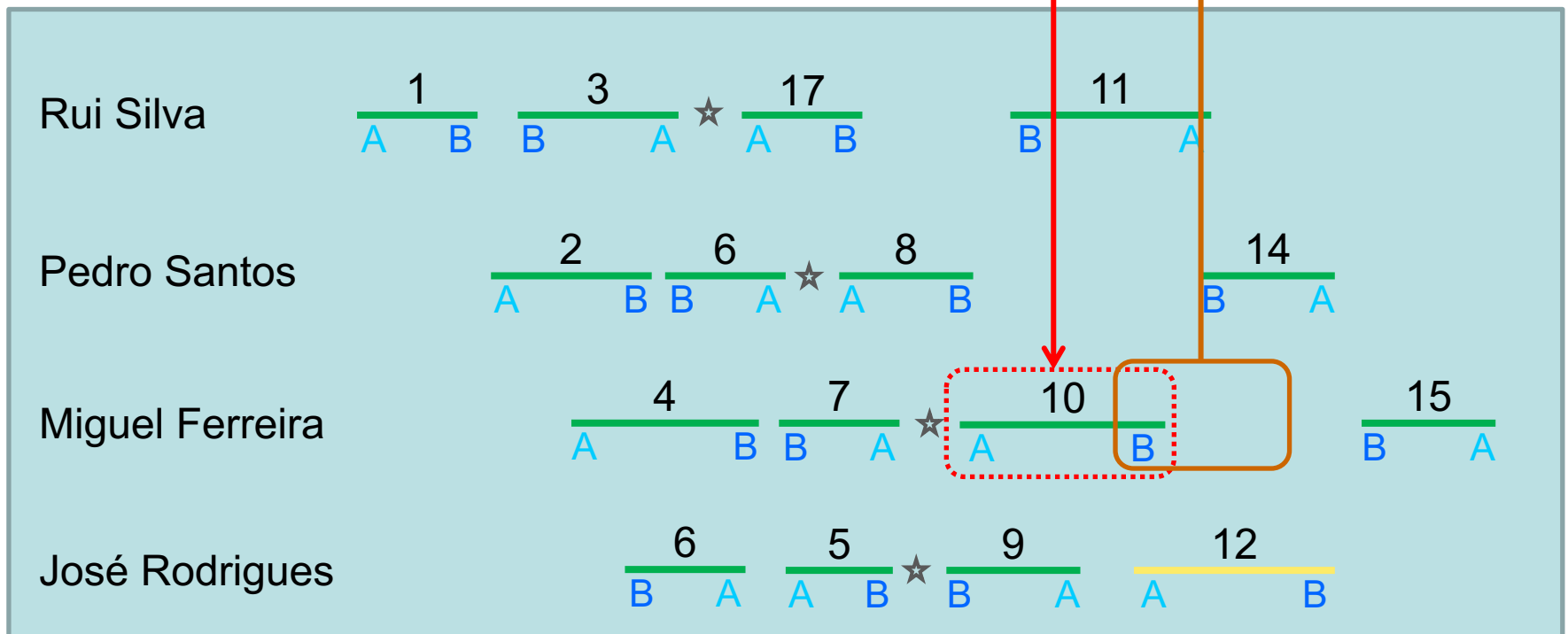
Desafio (exemplo)



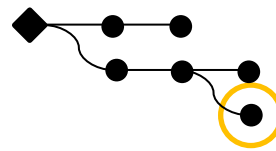
C. Tarefas = 4

C. Turnos = 19

Total (CT) = 23



Desafio (exemplo)



C. Tarefas = 4

C. Turnos = 19

Total (CT) = 23

13
A B

Rui Silva

1 3 17 11
A B B A A B B A

Pedro Santos

2 6 8 14
A B B A A B B A

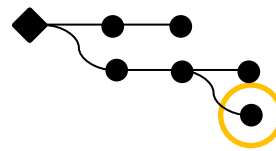
Miguel Ferreira

4 7 10 15
A B B A A B B A

José Rodrigues

6 5 9 12
B A A B B A A B

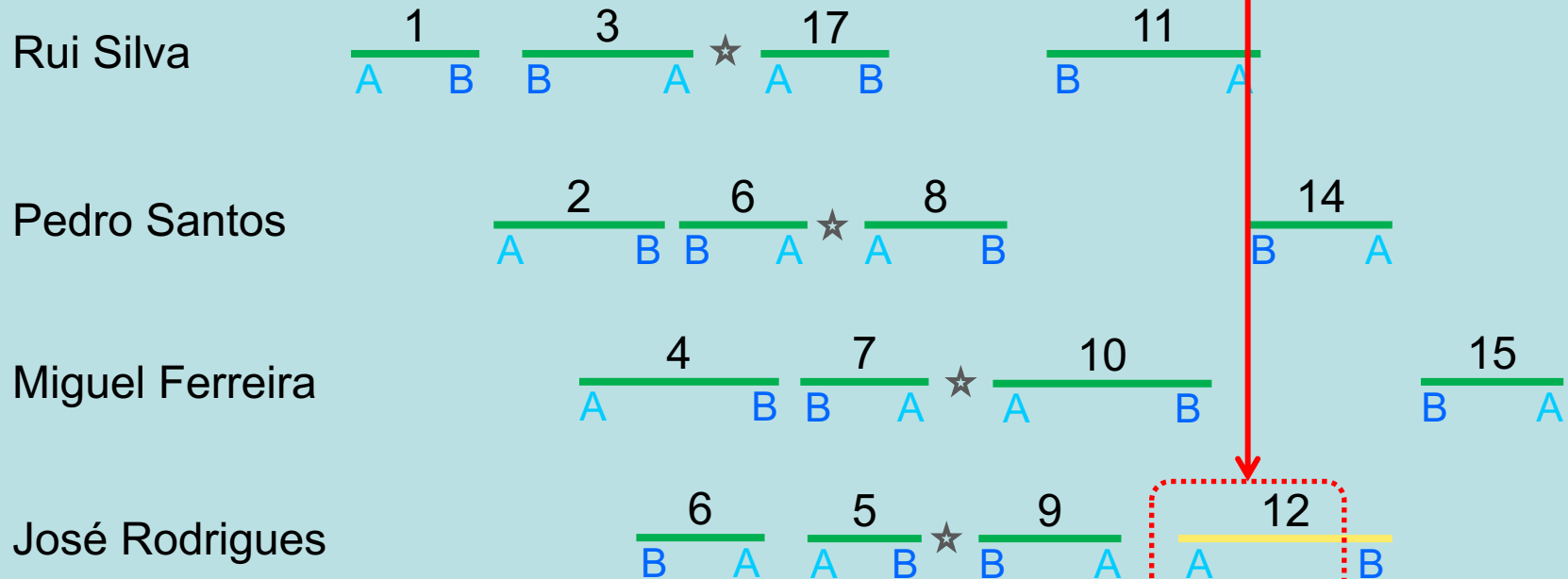
Desafio (exemplo)



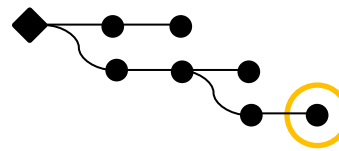
C. Tarefas = 4

C. Turnos = 19

Total (CT) = 23



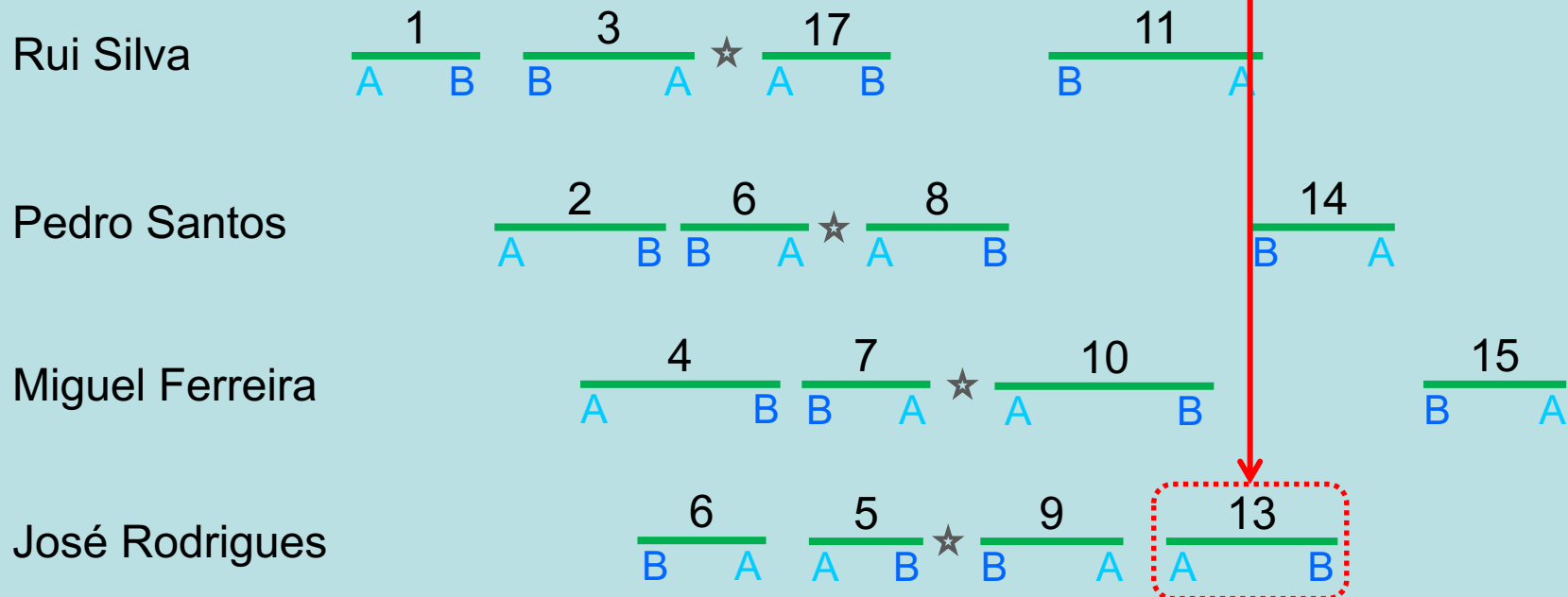
Desafio (exemplo)



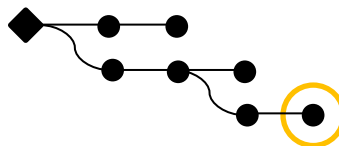
C. Tarefas = 0 (-4)

C. Turnos = 19

Total (CT) = 19 (-4)



Desafio (exemplo)



C. Tarefas = 0 (-4)

C. Turnos = 19

Total (CT) = 19 (-4)



Rui Silva

$\frac{1}{A \quad B}$	$\frac{3}{B \quad A}$	★	$\frac{17}{A \quad B}$	$\frac{11}{B \quad A}$
-----------------------	-----------------------	---	------------------------	------------------------

Pedro Santos

$\frac{2}{A \quad B}$	$\frac{6}{B \quad A}$	★	$\frac{8}{A \quad B}$	$\frac{14}{B \quad A}$
-----------------------	-----------------------	---	-----------------------	------------------------

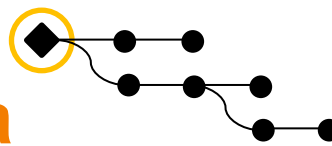
Miguel Ferreira

$\frac{4}{A \quad B}$	$\frac{7}{B \quad A}$	★	$\frac{10}{A \quad B}$	$\frac{15}{B \quad A}$
-----------------------	-----------------------	---	------------------------	------------------------

José Rodrigues

$\frac{6}{B \quad A}$	$\frac{5}{A \quad B}$	★	$\frac{9}{B \quad A}$	$\frac{13}{A \quad B}$
-----------------------	-----------------------	---	-----------------------	------------------------

Como guiar a procura



C. Tarefas = 4

C. Turnos = 19

Total (CT) = 23

17
A B

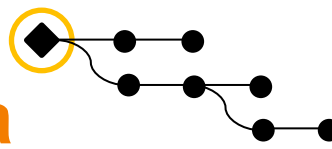
Rui Silva 1 3 ★ 8 11
A B B A A B B A

Pedro Santos 2 6 ★ 10 14
A B B A A B B A

Miguel Ferreira 4 7 ★ 13 15
A B B A A B B A

José Rodrigues 6 5 ★ 9 12
B A A B B A A B

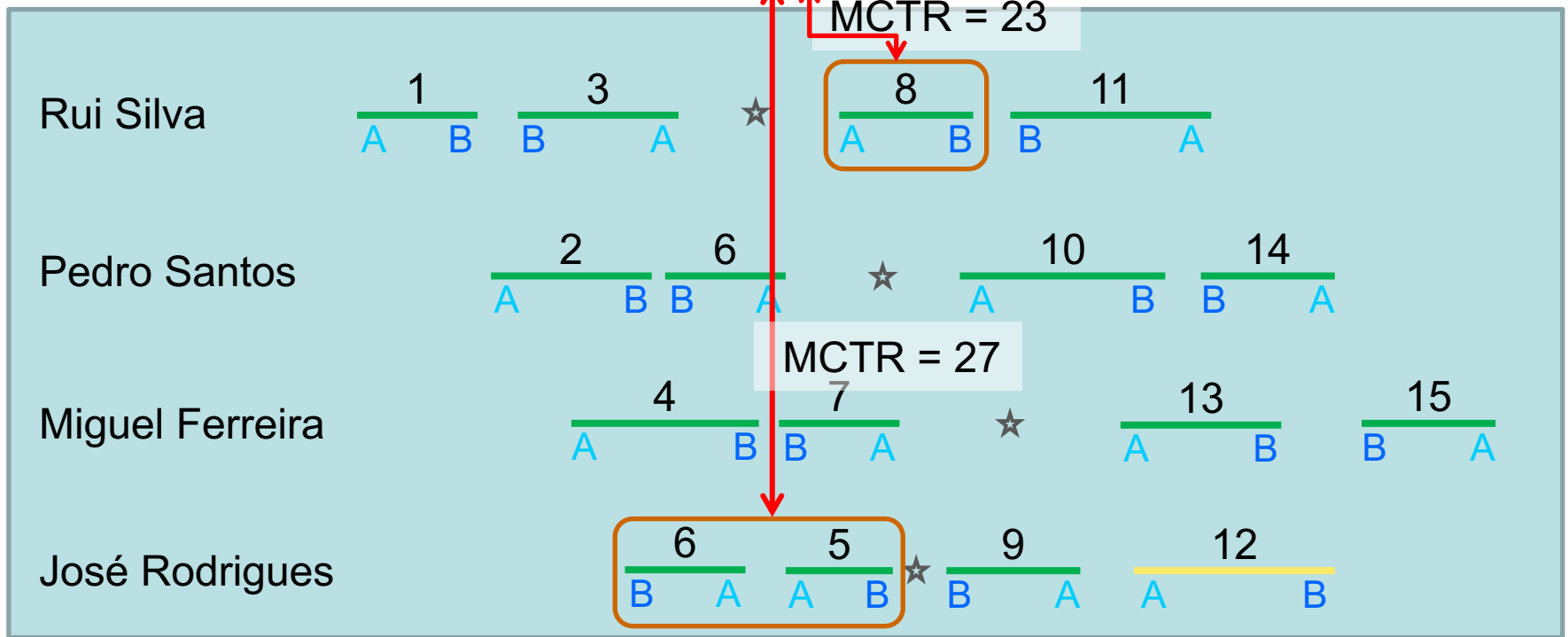
Como guiar a procura



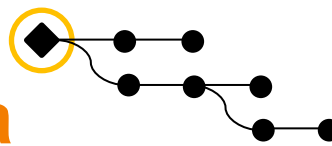
C. Tarefas = 4

C. Turnos = 19

Total (CT) = 23



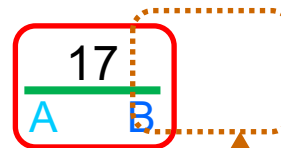
Como guiar a procura



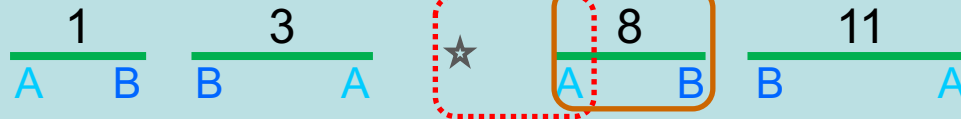
C. Tarefas = 4

C. Turnos = 19

Total (CT) = 23



Rui Silva



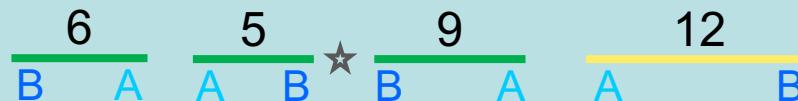
Pedro Santos



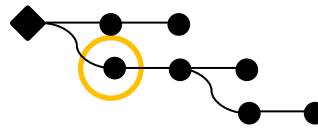
Miguel Ferreira



José Rodrigues



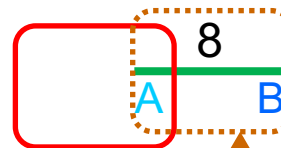
Como guiar a procura



C. Tarefas = 4

C. Turnos = 19

Total (CT) = 23



Rui Silva

1	3	★ 17	11
<u>A B</u>	<u>B A</u>	<u>A B</u>	<u>B A</u>

Pedro Santos

2	6	★	10	14
<u>A B</u>	<u>B A</u>		<u>A B</u>	<u>B A</u>

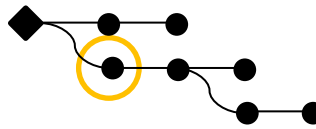
Miguel Ferreira

4	7	★	13	15
<u>A B</u>	<u>B A</u>		<u>A B</u>	<u>B A</u>

José Rodrigues

6	5	★	9	12
<u>B A</u>	<u>A B</u>		<u>B A</u>	<u>A B</u>

Como guiar a procura



C. Tarefas = 4

C. Turnos = 19

Total (CT) = 23

8
A B

Rui Silva

1 3 17 11
A B B A A B B A

Pedro Santos

2 6 10 14
A B B A A B B A

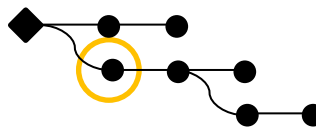
Miguel Ferreira

4 7 13 15
A B B A A B B A

José Rodrigues

6 5 9 12
B A A B B A A B

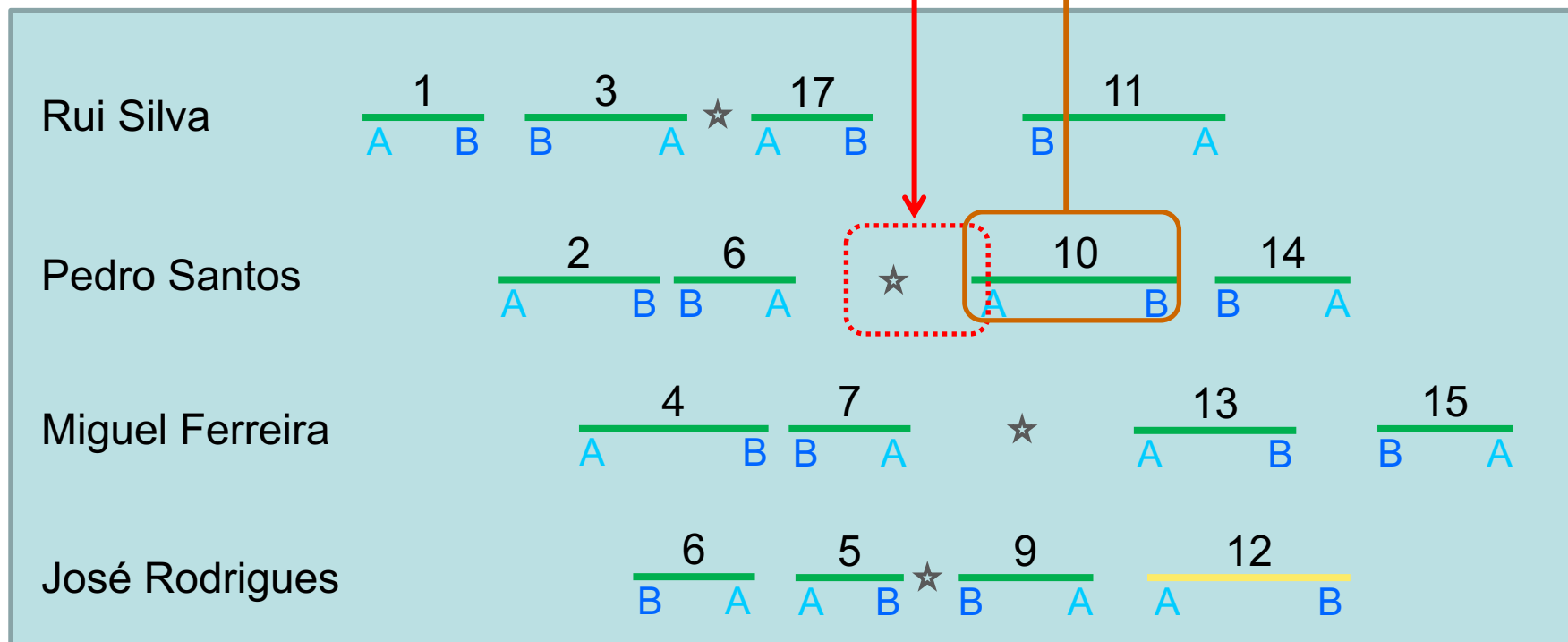
Como guiar a procura



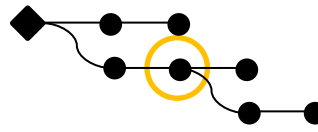
C. Tarefas = 4

C. Turnos = 19

Total (CT) = 23



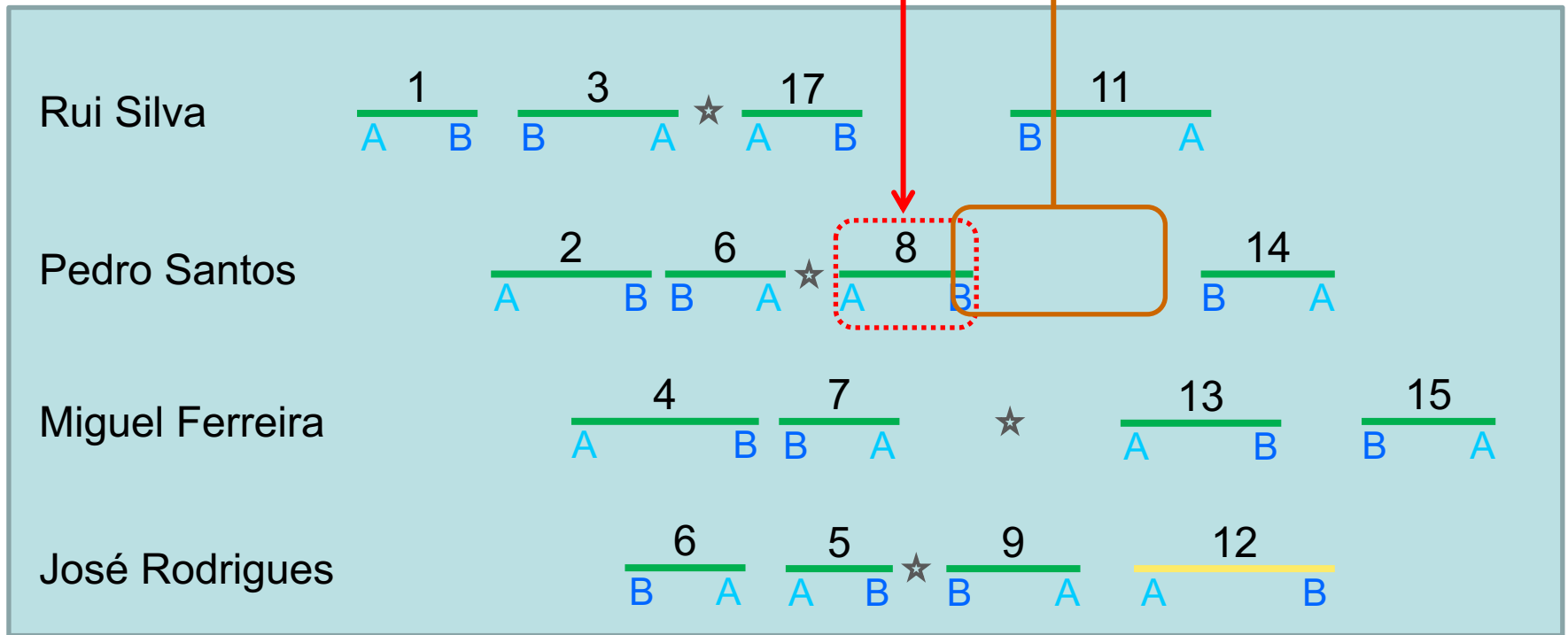
Como guiar a procura



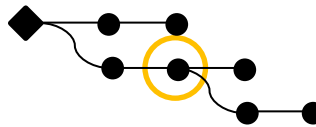
C. Tarefas = 4

C. Turnos = 19

Total (CT) = 23



Como guiar a procura



C. Tarefas = 4

C. Turnos = 19

Total (CT) = 23



Rui Silva



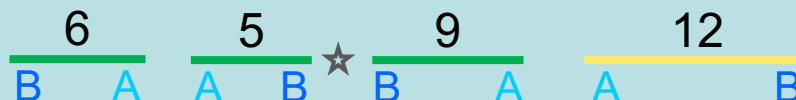
Pedro Santos



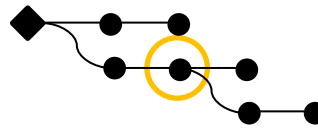
Miguel Ferreira



José Rodrigues



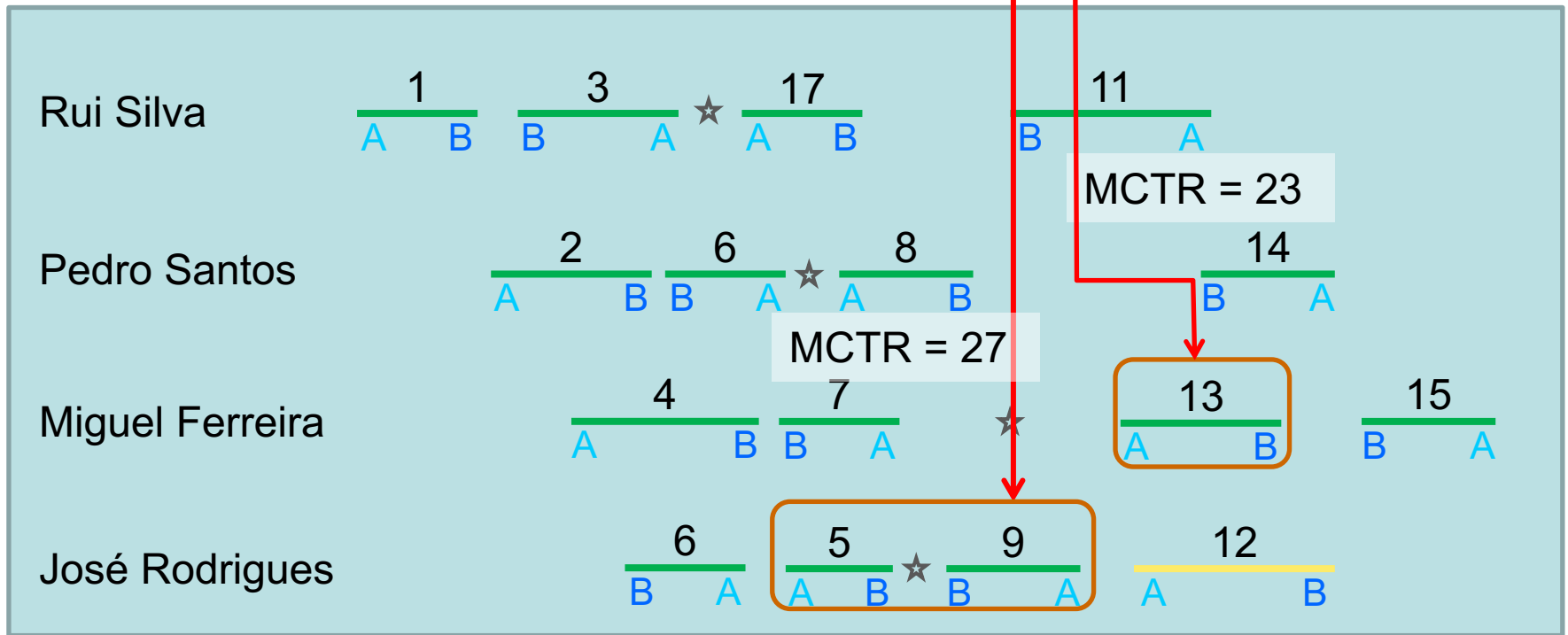
Como guiar a procura



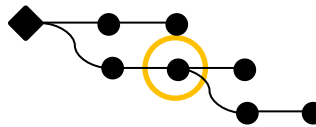
C. Tarefas = 4

C. Turnos = 19

Total (CT) = 23



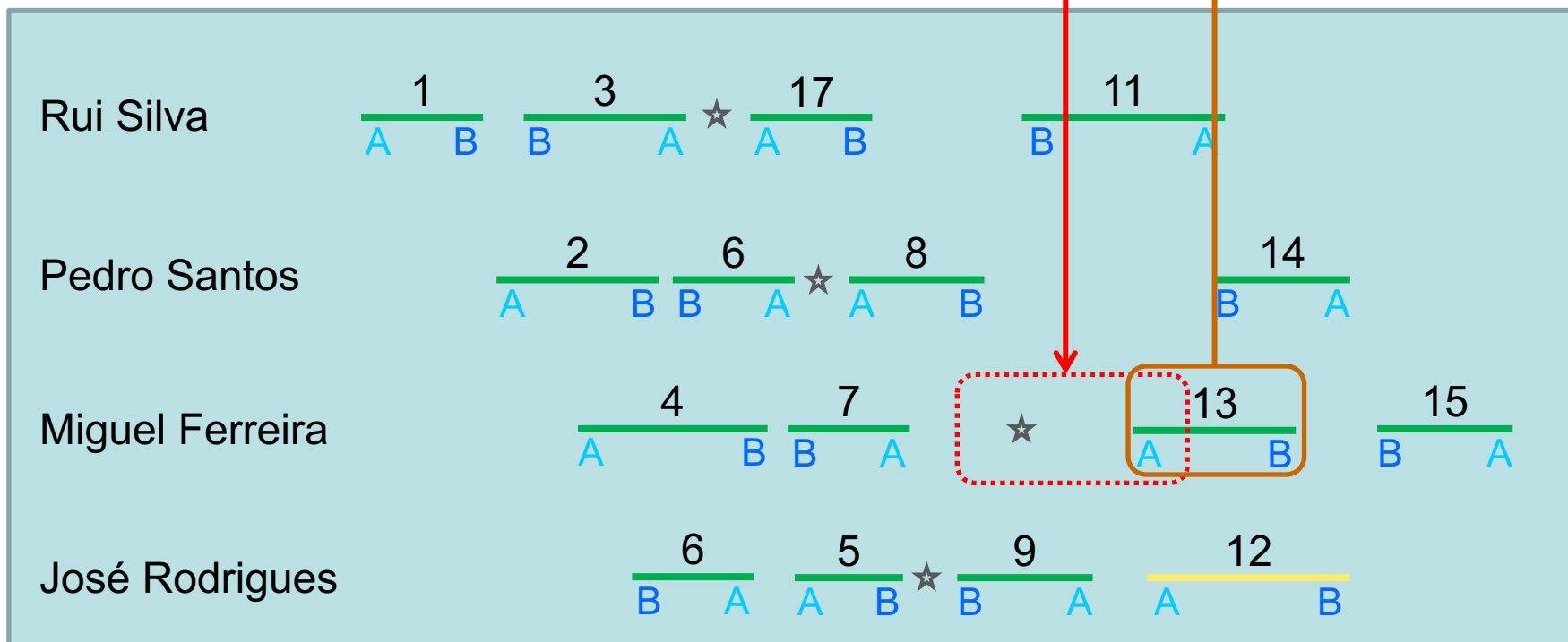
Como guiar a procura



C. Tarefas = 4

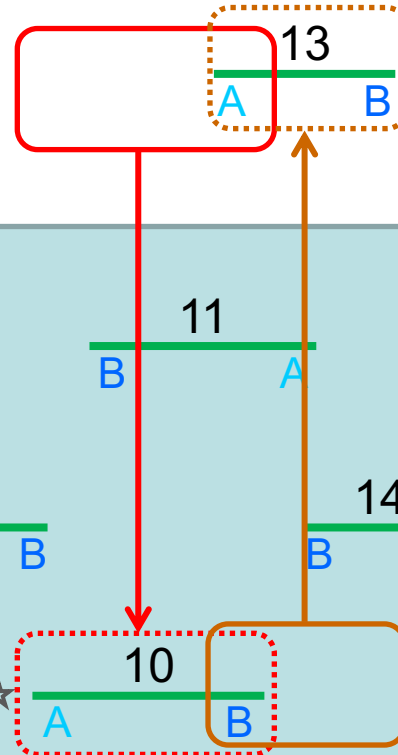
C. Turnos = 19

Total (CT) = 23

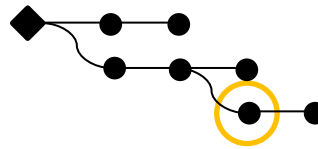


A directed graph with 7 nodes and 6 edges. The nodes are arranged in a zig-zag pattern. The bottom-most node is highlighted with a yellow circle.

Total (CT) = 23



Como guiar a procura



C. Tarefas = 4

C. Turnos = 19

Total (CT) = 23

13
A B

Rui Silva

1 3 17 11
A B B A A B B A

Pedro Santos

2 6 8 14
A B B A A B B A

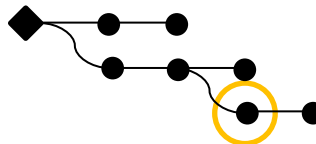
Miguel Ferreira

4 7 10 15
A B B A A B B A

José Rodrigues

6 5 9 12
B A A B B A A B

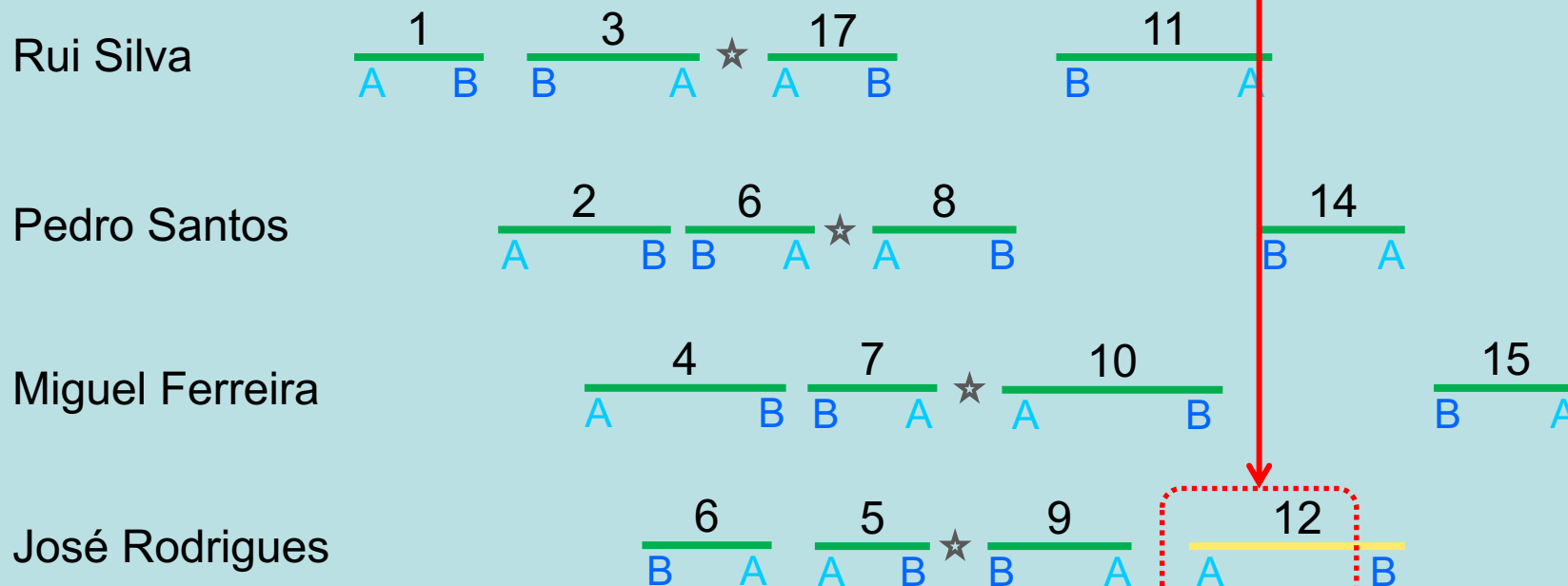
Como guiar a procura



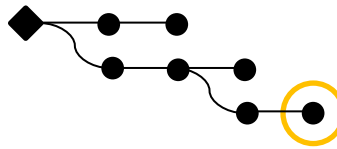
C. Tarefas = 4

C. Turnos = 19

Total (CT) = 23



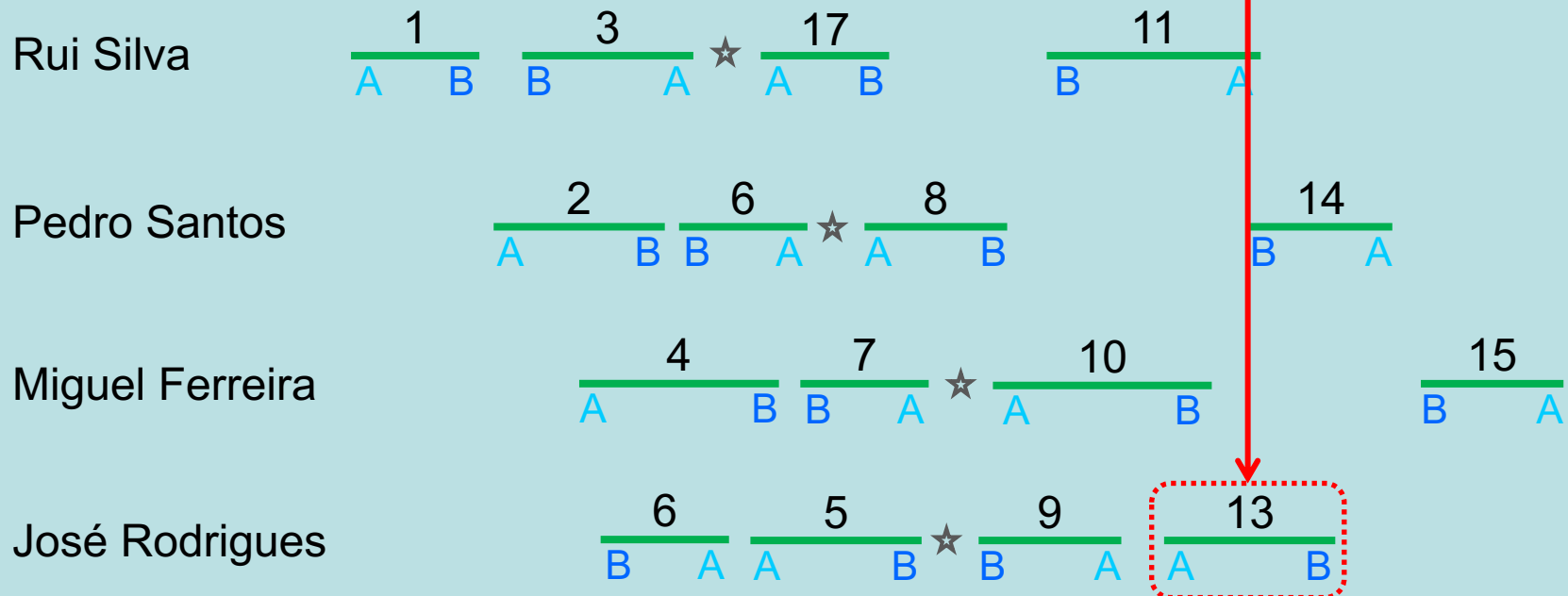
Como guiar a procura



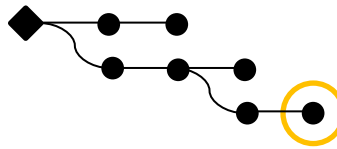
C. Tarefas = 0 (-4)

C. Turnos = 19

Total (CT) = 19 (-4)



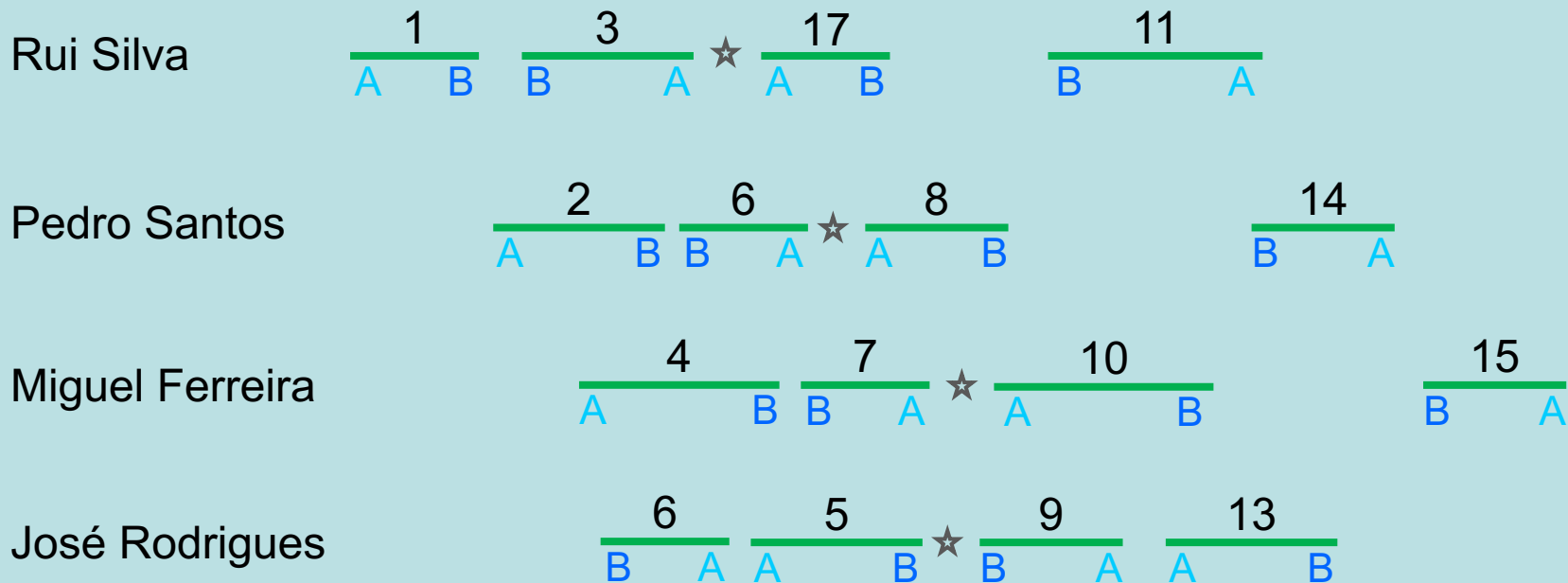
Como guiar a procura



C. Tarefas = 0 (-4)

C. Turnos = 19

Total (CT) = 19 (-4)



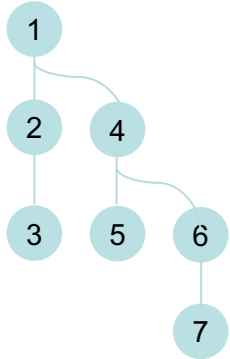
Procura Local (PL) actual

- Árvore explorada em profundidade primeiro
- Vizinhança (decisões alternativas)
 - Decisão 1: planejar tarefa t no turno do tripulante x
 - Decisão 2: planejar tarefa t no turno do tripulante y
 - Decisão 3: planejar tarefa t no turno do tripulante z
 - Decisão n :...
- Escolhe primeiro o vizinho com menor **MCTR**
- Retrocede sempre que CT ultrapassa determinado valor
- Melhor Custo Total Resultante (MCTR)
 - $MCTR(\text{estado}, \text{decisão})$
 - Estimativa demasiado grosseira
 - Muitos retrocessos

Objectivo do desafio

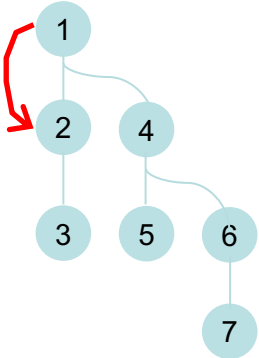
- Melhorar PL substituindo MCTR por MCTR'
 - $MCTR'(p_1, \dots, p_M, c_1, \dots, c_N)$
 - Pesos p_1, \dots, p_M mantêm-se fixos durante a procura
 - Características c_1, \dots, c_N variam ao longo da procura
 - Dependem do estado e da decisão
- Desafio
 - Determinar a função MCTR' (modelo de aprendizagem)
 - Determinar os pesos p_1, \dots, p_M com base num histórico
 - Determinar as características c_1, \dots, c_N relevantes
 - Objectivo: MCTR' preveja melhor que MCTR → melhores soluções em menos tempo
- Histórico
 - Ficheiros com *traces* de corridas da PL

Trace de uma corrida



Trace de uma corrida

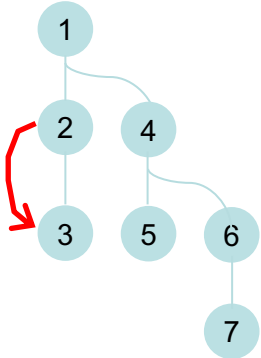
F 1 2 <características> <CT de 2>



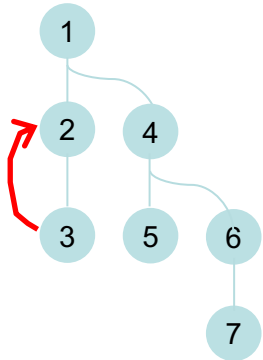
Trace de uma corrida

F 1 2 <características> <CT de 2>

F 2 3 <características> <CT de 3>



Trace de uma corrida

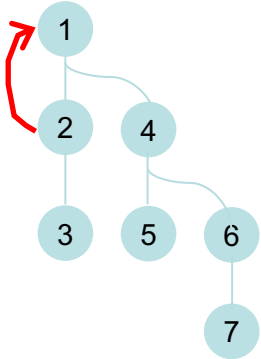


F 1 2 <características> <CT de 2>

F 2 3 <características> <CT de 3>

B 3 2

Trace de uma corrida



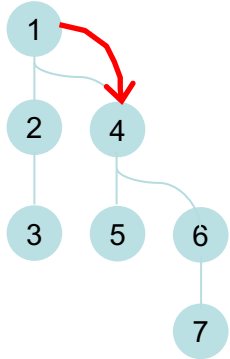
F 1 2 <características> <CT de 2>

F 2 3 <características> <CT de 3>

B 3 2

B 2 1

Trace de uma corrida



F 1 2 <características> <CT de 2>

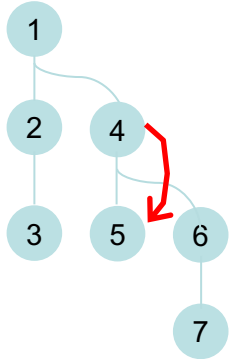
F 2 3 <características> <CT de 3>

B 3 2

B 2 1

F 1 4 <características> <CT de 4>

Trace de uma corrida



F 1 2 <características> <CT de 2>

F 2 3 <características> <CT de 3>

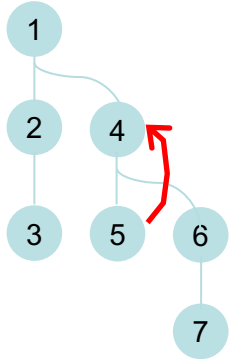
B 3 2

B 2 1

F 1 4 <características> <CT de 4>

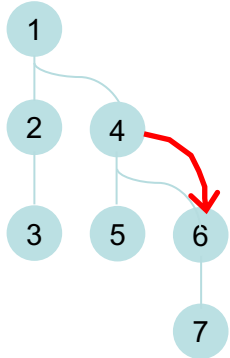
F 4 5 <características> <CT de 5>

Trace de uma corrida



F 1 2 <características> <CT de 2>
F 2 3 <características> <CT de 3>
B 3 2
B 2 1
F 1 4 <características> <CT de 4>
F 4 5 <características> <CT de 5>
B 5 4

Trace de uma corrida



F 1 2 <características> <CT de 2>

F 2 3 <características> <CT de 3>

B 3 2

B 2 1

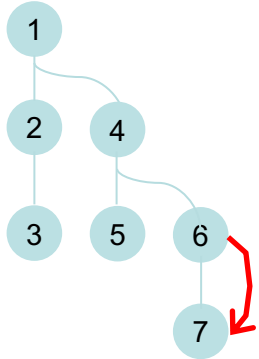
F 1 4 <características> <CT de 4>

F 4 5 <características> <CT de 5>

B 5 4

F 4 6 <características> <CT de 6>

Trace de uma corrida



F 1 2 <características> <CT de 2>

F 2 3 <características> <CT de 3>

B 3 2

B 2 1

F 1 4 <características> <CT de 4>

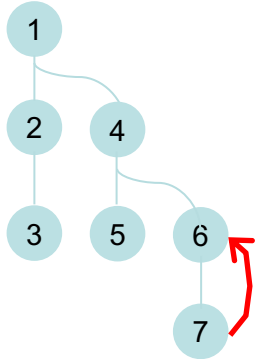
F 4 5 <características> <CT de 5>

B 5 4

F 4 6 <características> <CT de 6>

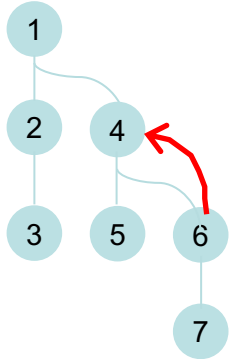
F 6 7 <características> <CT de 7>

Trace de uma corrida



F 1 2 <características> <CT de 2>
F 2 3 <características> <CT de 3>
B 3 2
B 2 1
F 1 4 <características> <CT de 4>
F 4 5 <características> <CT de 5>
B 5 4
F 4 6 <características> <CT de 6>
F 6 7 <características> <CT de 7>
B 7 6

Trace de uma corrida



F 1 2 <características> <CT de 2>

F 2 3 <características> <CT de 3>

B 3 2

B 2 1

F 1 4 <características> <CT de 4>

F 4 5 <características> <CT de 5>

B 5 4

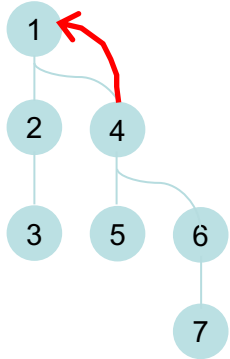
F 4 6 <características> <CT de 6>

F 6 7 <características> <CT de 7>

B 7 6

B 6 4

Trace de uma corrida



F 1 2 <características> <CT de 2>

F 2 3 <características> <CT de 3>

B 3 2

B 2 1

F 1 4 <características> <CT de 4>

F 4 5 <características> <CT de 5>

B 5 4

F 4 6 <características> <CT de 6>

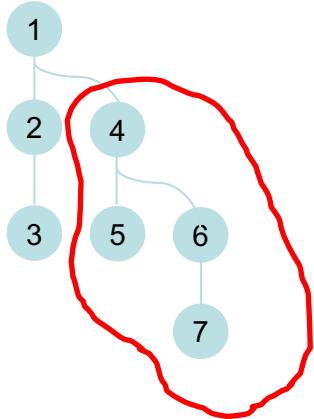
F 6 7 <características> <CT de 7>

B 7 6

B 6 4

B 4 1

Trace de uma corrida



F 1 2 <características> <CT de 2>

F 2 3 <características> <CT de 3>

B 3 2

B 2 1

F 1 4 <características> <CT de 4>

F 4 5 <características> <CT de 5>

B 5 4

F 4 6 <características> <CT de 6>

F 6 7 <características> <CT de 7>

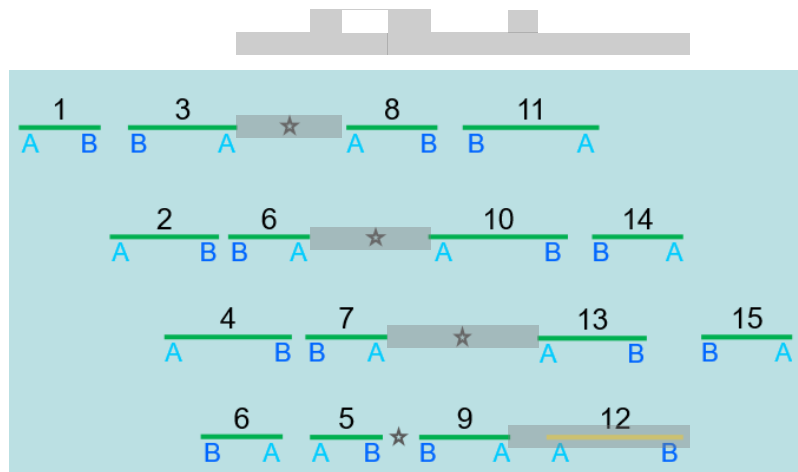
B 7 6

B 6 4

B 4 1

Características

- Custo total do estado antes da decisão
- Número de tarefas por planear antes da decisão
- Variação no número de tarefas por planear
- Variação na duração do turno
- Variação no espaço livre dos turnos para receber tarefas
- Variação no número de turnos modificados
- Outras?



Desafio (resumo)

- Determinar a função $MCTR'$ (modelo de aprendizagem)
- Determinar os pesos p_1, \dots, p_M com base no histórico
 - Como é que isto é feito?
- Determinar as características c_1, \dots, c_N relevantes
- Objectivo: $MCTR'$ preveja melhor que $MCTR \rightarrow$ melhores soluções em menos tempo



Obrigados
Obrigado

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