Best-First Search
Minimizing Space or Time

RBFS

Save space, take more time

RBFS general properties

- Similar to A* algorithm developed for heuristic search

RBFS general properties – 2

- ◊ Similar to A* algorithm developed for heuristic search
  - » **Both are recursive in the same sense**

RBFS general properties – 3

- Similar to A* algorithm developed for heuristic search
  - **Both are recursive in the same sense**
- Difference between A* and RBFS

RBFS general properties – 3

- Similar to A* algorithm developed for heuristic search
  - **Both are recursive in the same sense**

- Difference between A* and RBFS
  - **A* keeps in memory all of the already generated nodes**

RBFS general properties – 4

- ◊ Similar to A* algorithm developed for heuristic search
  - » **Both are recursive in the same sense**
- ◊ Difference between A* and RBFS
  - » **A* keeps in memory all of the already generated nodes**
  - » **RBFS only keeps the current search path and the sibling nodes along the path**

RBFS space – 2

» **When does RBFS suspend the search of a subtree?**

RBFS space – 3

- When does RBFS suspend the search of a subtree?
  - When it no longer looks the best

RBFS space – 3

» When does RBFS suspend the search of a subtree?

  > When it no longer looks the best

» What does it do when a subtree is suspended?

RBFS space – 3

- When does RBFS suspend the search of a subtree?
  - When it no longer looks the best

- What does it do when a subtree is suspended?
  - It forgets the subtree to save space

RBFS space – 4

- When does RBFS suspend the search of a subtree?
  - When it no longer looks the best

- What does it do when a subtree is suspended?
  - It forgets the subtree to save space

- What is the space complexity?

RBFS space – 5

» When does RBFS suspend the search of a subtree?
  > When it no longer looks the best

» What does it do when a subtree is suspended?
  > It forgets the subtree to save space

» What is the space complexity?
  > Linear the depth of the search

RBFS space – 6

» When does RBFS suspend the search of a subtree?
  > When it no longer looks the best

» What does it do when a subtree is suspended?
  > It forgets the subtree to save space

» What is the space complexity?
  > Linear the depth of the search
    – Same as IDA*

RBFS memory

» **When RBFS suspends searching a subtree, what does it remember?**

RBFS memory – 2

» When RBFS suspends searching a subtree, what does it remember?

> An updated f-value of the root of the subtree

Updated f-values

» **How does RBFS update the f-values?**

Updated f-values – 2

» **How does RBFS update the f-values?**

> **Backing up the f-values in the same way as A* does**

f-value notation

- Static f-value
  - **f(N)**
    - **Value returned by the evaluation function**
    - **Always the same**

f-value notation – 2

- Static f-value
  - » f(N)
    - > Value returned by the evaluation function
    - > Always the same
- Backed-up value
  - » F(N)
    - > Changes during the search
      - – **Depends upon descendants of N**

F(N) definition

◊ RBFS backs up f-values in the same way as A*

» **How is F(N) defined?**

F(N) definition – 2

- ◊ RBFS backs up f-values in the same way as A*
  - » **How is F(N) defined?**
    - > **If N has never been expanded?**

F(N) definition – 3

◊ RBFS backs up f-values in the same way as A*

» **How is F(N) defined?**

> **If N has never been expanded?**

– **F(N) = f(N)**

F(N) definition – 4

◊ RBFS backs up f-values in the same way as A*

» **How is F(N) defined?**

> **If N has never been expanded?**

– $\mathbf{F(N) = f(N)}$

> **If N has been expanded?**

F(N) definition – 5

◊ RBFS backs up f-values in the same way as A*

» **How is F(N) defined?**

> **If N has never been expanded?**

– $F(N) = f(N)$

> **If N has been expanded?**

– $F(N) = \min (F (S_j))$

– **Where S_j are the subtrees of N**

Subtree exploration

» **How does RBFS explore subtrees?**

Subtree exploration – 2

» How does RBFS explore subtrees?

> As in A*, within a given f-bound

Subtree exploration – 3

» **How does RBFS explore subtrees?**

> **As in A*, within a given f-bound**

» **How is the bound determined?**

RBFS subtree exploration – 4

» How does RBFS explore subtrees?

> As in A*, within a given f-bound

» How is the bound determined?

> From the F-values of the siblings along the current search path

Subtree exploration – 5

» How does RBFS explore subtrees?

> As in A*, within a given f-bound

» How is the bound determined?

> From the F-values of the siblings along the current search path

> The smallest F-value

– The closest competitor

Subtree exploration – 6

◊ Suppose N is currently the best node

Subtree exploration – 7

◊ Suppose N is currently the best node

  > **N is expanded**

Subtree exploration – 8

- ◊ Suppose N is currently the best node
  - > **N is expanded**
  - > **N's children are expanded**

Subtree exploration – 9

◊ Suppose N is currently the best node

> > **N is expanded**
>
> > **N's children are expanded**

» **Until when?**

Subtree exploration – 10

◊ Suppose N is currently the best node

> N is expanded

> N's children are expanded

» Until when?

> F(N) > Bound

Subtree exploration – 10

- ◊ Suppose N is currently the best node
  - > **N is expanded**
  - > **N's children are expanded**

- » **Until when?**
  - > **F(N) > Bound**

- » **Then what happens?**

Subtree exploration – 11

- ◊ Suppose N is currently the best node
  - > **N is expanded**
  - > **N's children are expanded**

- » **Until when?**
  - > **F(N) > Bound**

- » **Then what happens?**
  - > **Nodes below N are forgotten**

Subtree exploration – 12

◊ Suppose N is currently the best node

> N is expanded

> N's children are expanded

» Until when?

> F(N) > Bound

» Then what happens?

> Nodes below N are forgotten

> N's F-value is updated

Subtree exploration – 13

- Suppose N is currently the best node
  - **N is expanded**
  - **N's children are expanded**

  - **Until when?**
    - **F(N) > Bound**

  - **Then what happens?**
    - **Nodes below N are forgotten**
    - **N's F-value is updated**
    - **RBFS selects which node to expand next**

F-value inheritance

◊ F-values can be inherited from a node's parents

F-value inheritance – 2

- F-values can be inherited from a node's parents
- Let N be a node about to be expanded

F-value inheritance – 3

- F-values can be inherited from a node's parents
- Let N be a node about to be expanded
  - **If F(N) > f(N) then N had already been expanded**

F-value inheritance – 4

- F-values can be inherited from a node's parents
- Let N be a node about to be expanded
  - **If F(N) > f(N) then N had already been expanded**
  - **F(N) was determined from N's children**

F-value inheritance – 5

- ◊ F-values can be inherited from a node's parents
- ◊ Let N be a node about to be expanded
  - » **If F(N) > f(N) then N had already been expanded**
  - » **F(N) was determined from N's children**
  - » **Children have been removed from memory**

F-value inheritance – 6

- ◊ F-values can be inherited from a node's parents
- ◊ Let N be a node about to be expanded
  - » **If F(N) > f(N) then N had already been expanded**
  - » **F(N) was determined from N's children**
  - » **Children have been removed from memory**
- ◊ Suppose a child N_k of N is generated again

F-value inheritance – 7

- F-values can be inherited from a node's parents
- Let N be a node about to be expanded
  - **If F(N) > f(N) then N had already been expanded**
  - **F(N) was determined from N's children**
  - **Children have been removed from memory**
- Suppose a child N_k of N is generated again
  - **Compute f(N_k)**

F-value inheritance – 8

- F-values can be inherited from a node's parents
- Let N be a node about to be expanded
  - **If F(N) > f(N) then N had already been expanded**
  - **F(N) was determined from N's children**
  - **Children have been removed from memory**
- Suppose a child N_k of N is generated again
  - **Compute $f(N_k)$**
  - **$F(N_k) = \max(F(N), f(N_k))$**

F-value inheritance – 9

- F-values can be inherited from a node's parents
- Let N be a node about to be expanded
  - **If F(N) > f(N) then N had already been expanded**
  - **F(N) was determined from N's children**
  - **Children have been removed from memory**
- Suppose a child N_k of N is generated again
  - **Compute $f(N_k)$**
  - **$F(N_k) = \max(F(N), f(N_k))$**
    - **N_k's F-value can be inherited from N**

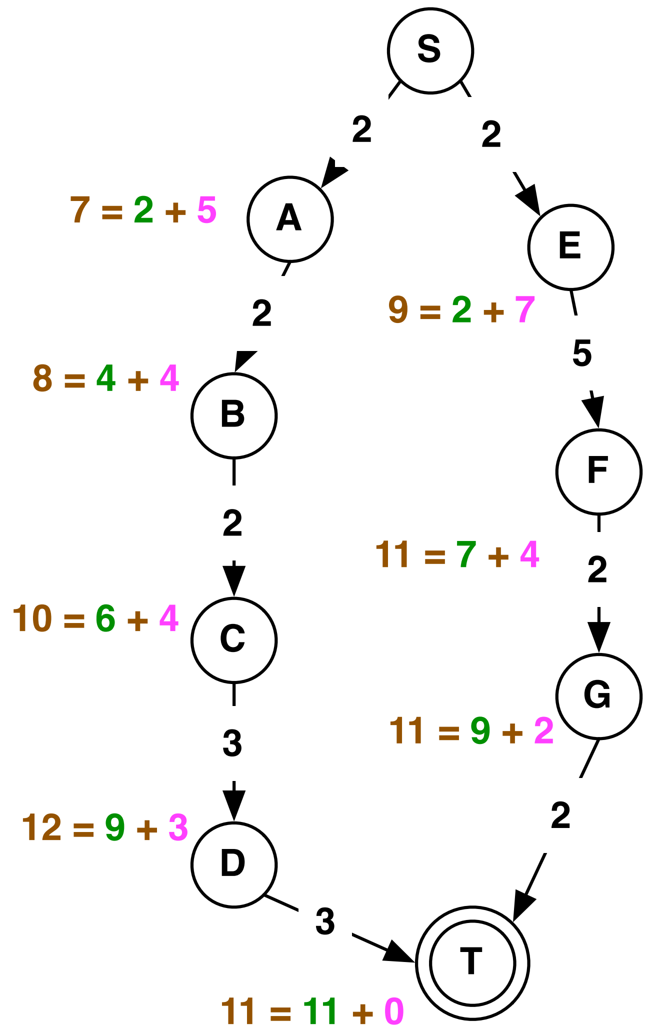
F-value inheritance – 10

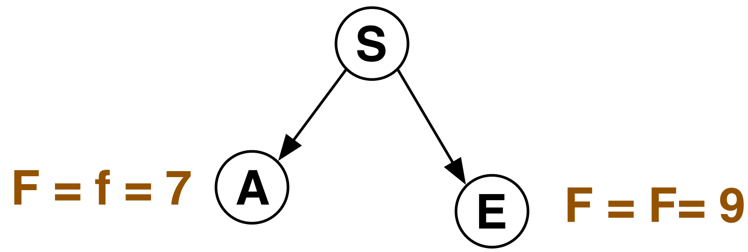
- ◊ F-values can be inherited from a node's parents
- ◊ Let N be a node about to be expanded
  - » **If F(N) > f(N) then N had already been expanded**
  - » **F(N) was determined from N's children**
  - » **Children have been removed from memory**
- ◊ Suppose a child N_k of N is generated again
  - » **Compute $f(N_k)$**
  - » **$F(N_k) = \max(F(N) , f(N_k))$**
    - > **N_k's F-value can be inherited from N**
      - – **N_k was generated earlier**

F-value inheritance – 11

- ◊ F-values can be inherited from a node's parents
- ◊ Let N be a node about to be expanded
  - » **If F(N) > f(N) then N had already been expanded**
  - » **F(N) was determined from N's children**
  - » **Children have been removed from memory**
- ◊ Suppose a child N_k of N is generated again
  - » **Compute $f(N_k)$**
  - » **$F(N_k) = \max(F(N), f(N_k))$**
    - > **N_k's F-value can be inherited from N**
      - – **N_k was generated earlier**
      - – **$F(N_k)$ was $\geq F(N)$, otherwise F(N) would be smaller**

Fig 12.2 snapshots



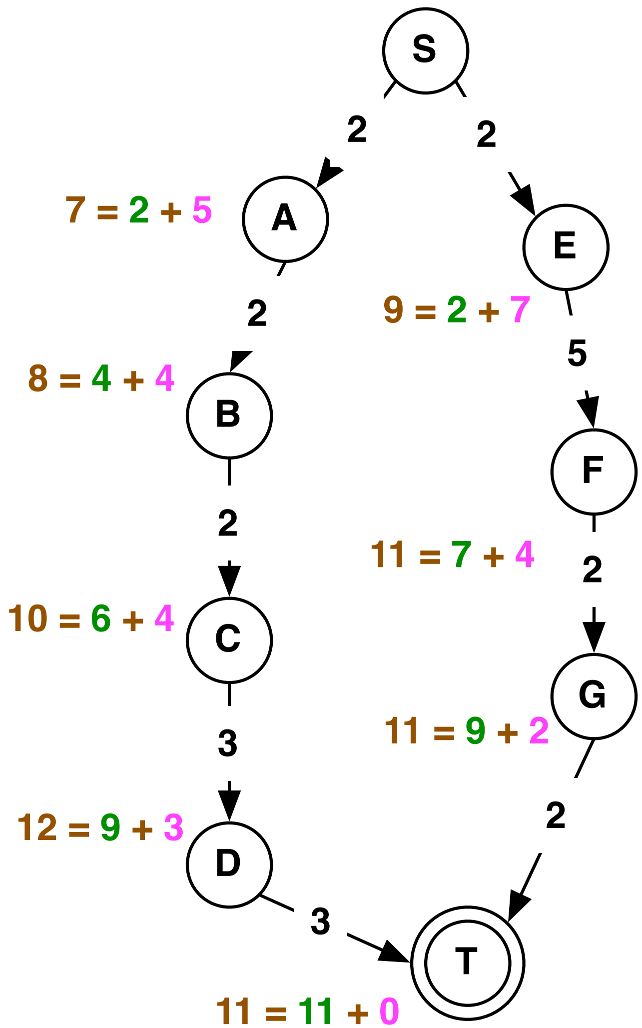


S is expanded

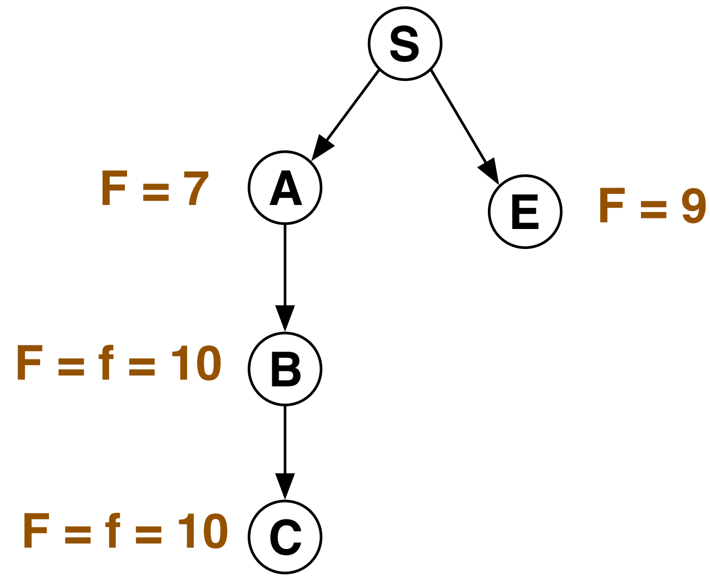
A is found to be the best child

f(n) in mocha = g(n) in clover + h(n) in magenta

Fig 12.2 snapshots – 2



f(n) in mocha = g(n) in clover + h(n) in magenta

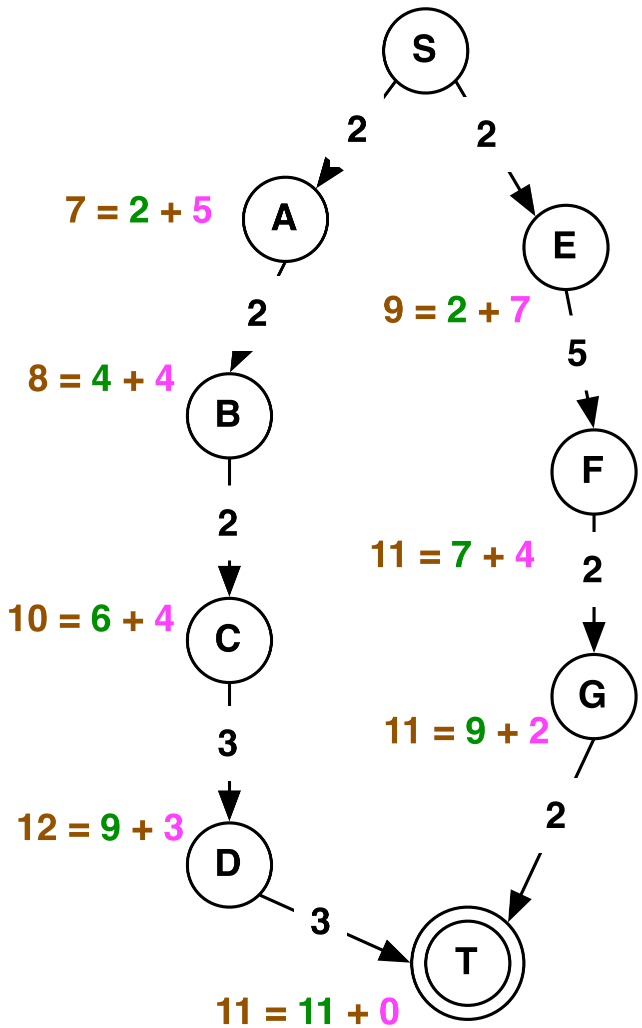


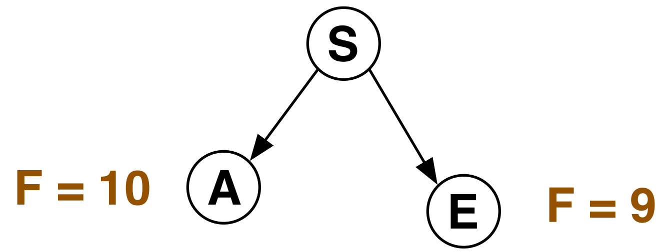
A is expanded with bound 9

C has F-value 10

Stop expansion, backup F value

Fig 12.2 snapshots – 3





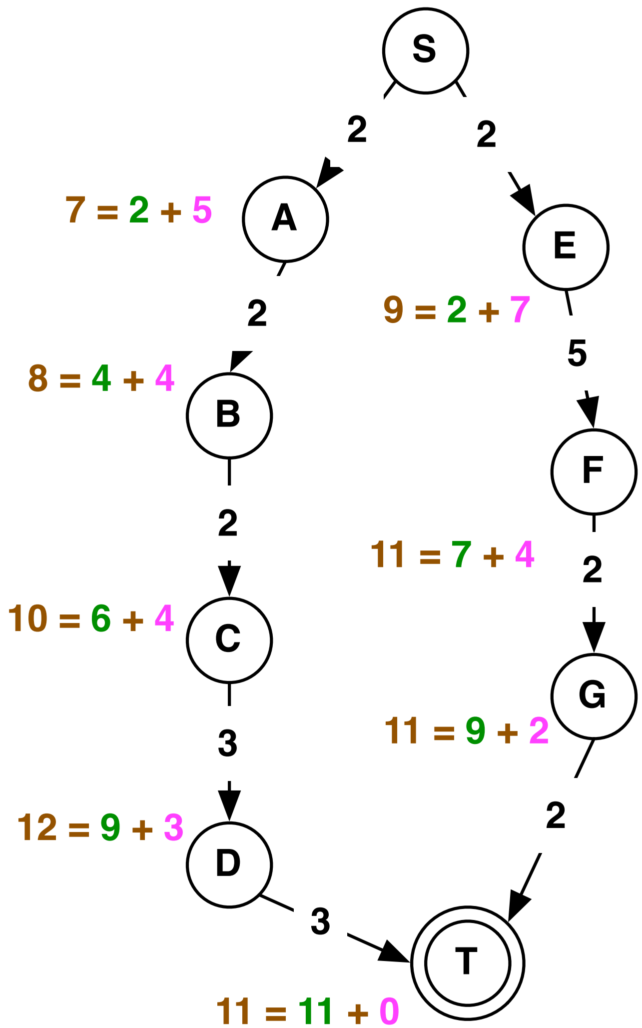
Forget expansion from A

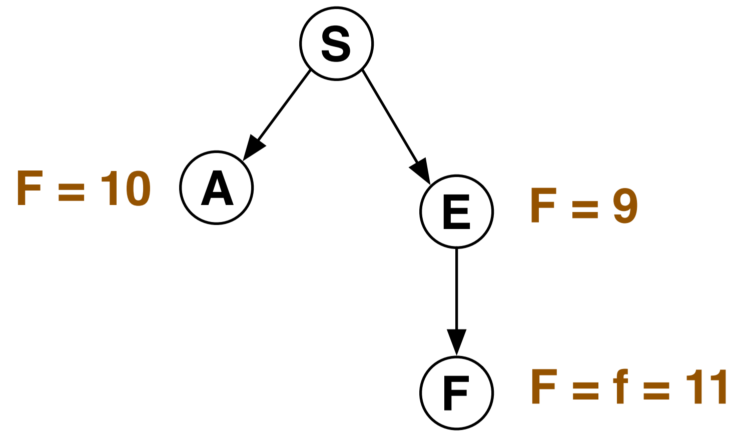
A has backed up F value 10

E is best to expand next

f(n) in mocha = g(n) in clover + h(n) in magenta

Fig 12.2 snapshots – 4





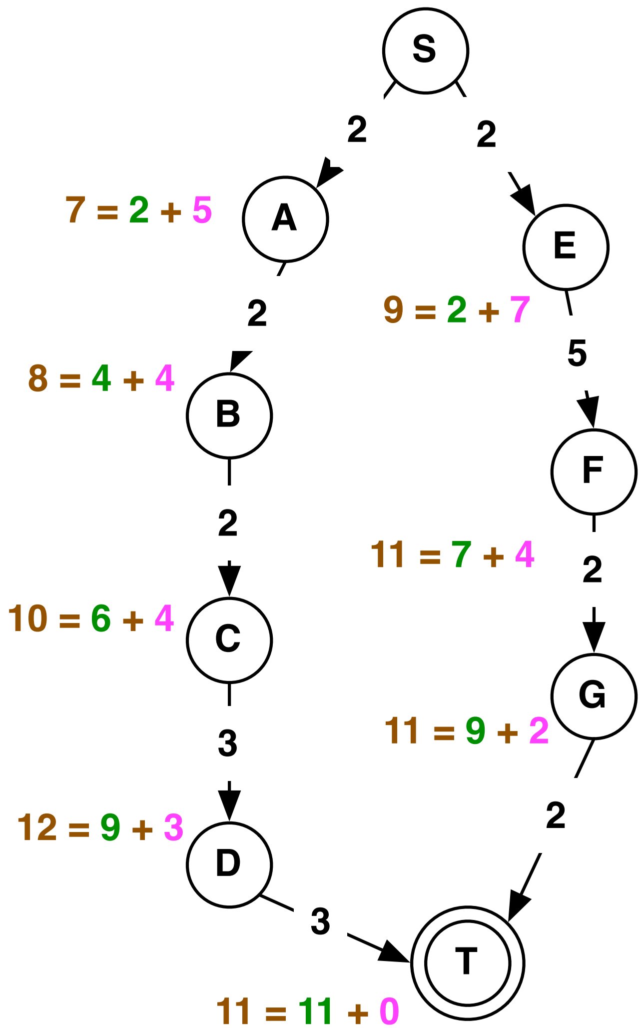
E is expanded with bound 10

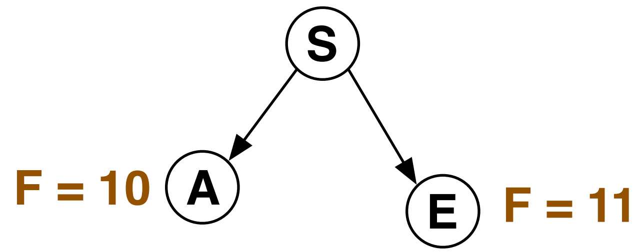
F has F-value 11

Stop expansion, backup F value

f(n) in mocha = g(n) in clover + h(n) in magenta

Fig 12.2 snapshots – 5





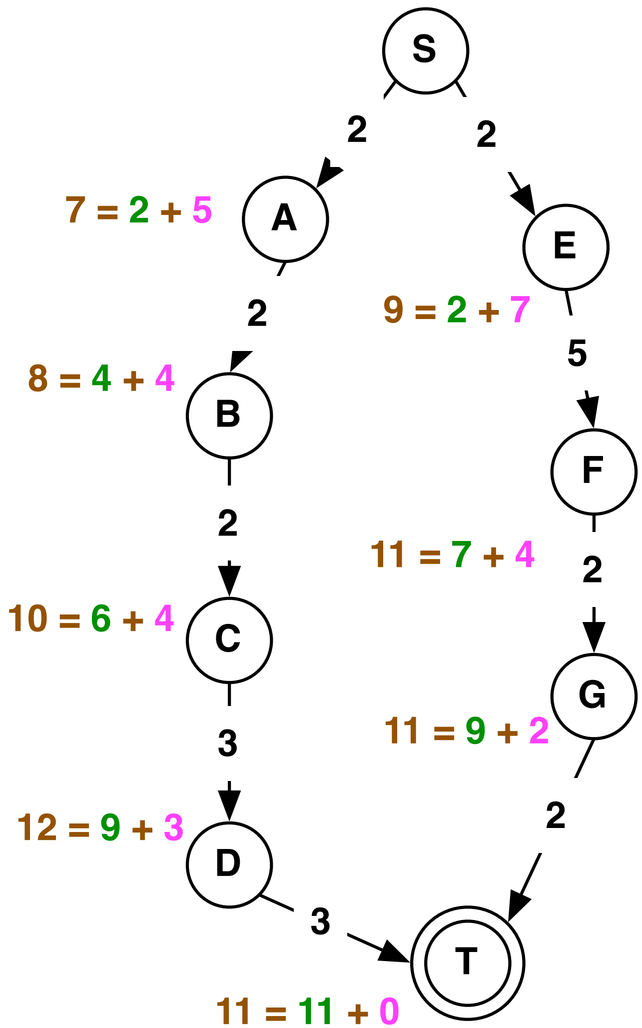
Forget expansion from E

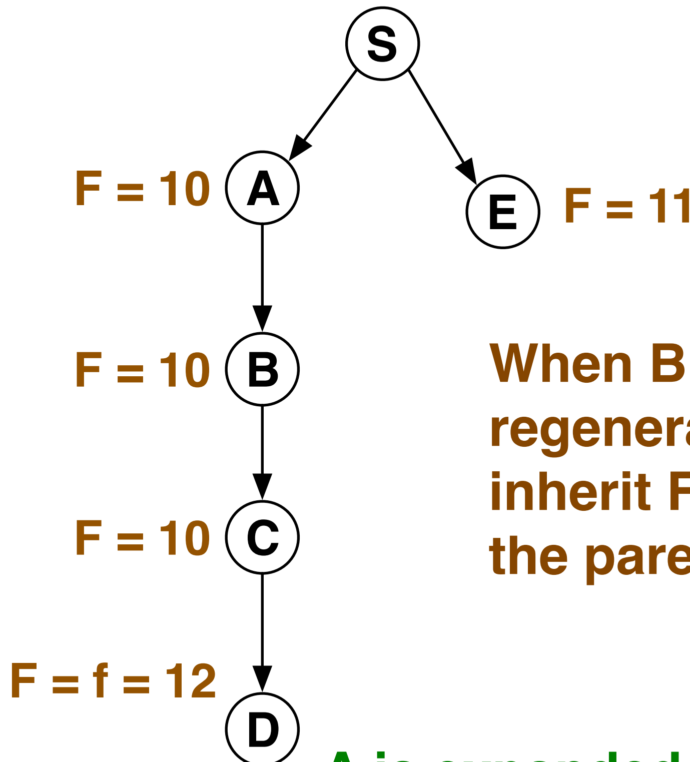
E has backed up F value 11

A is best to expand next

f(n) in mocha = g(n) in clover + h(n) in magenta

Fig 12.2 snapshots – 6





When B and C are regenerated, they inherit F value 10 from the parent

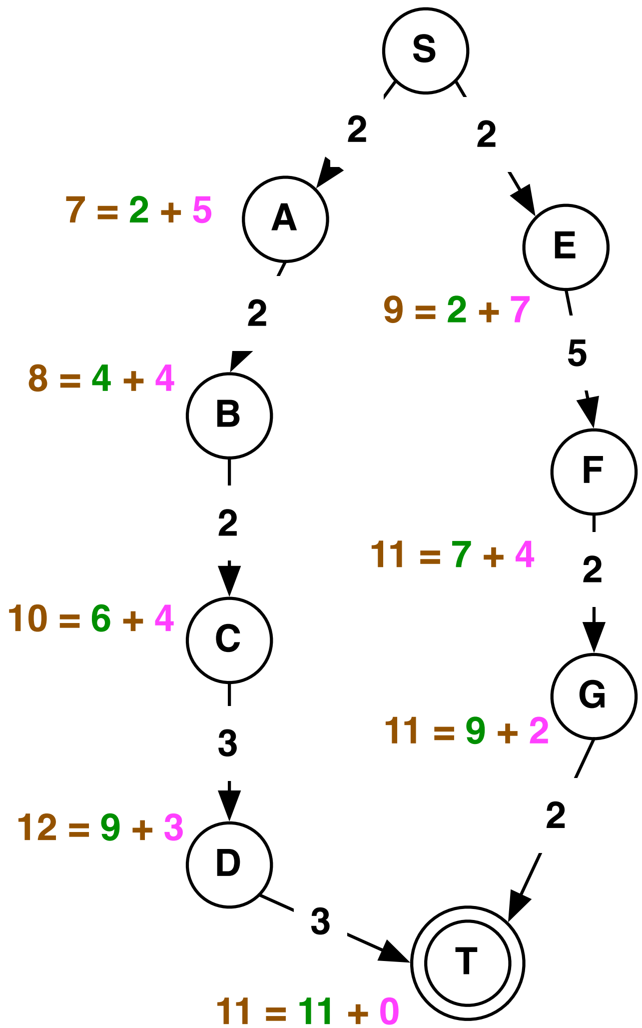
A is expanded with bound 11

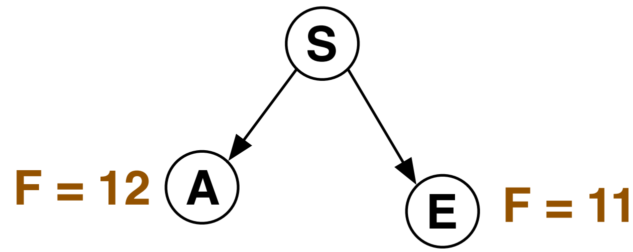
D has F-value 12

Stop expansion, backup F value

f(n) in mocha = g(n) in clover + h(n) in magenta

Fig 12.2 snapshots – 7





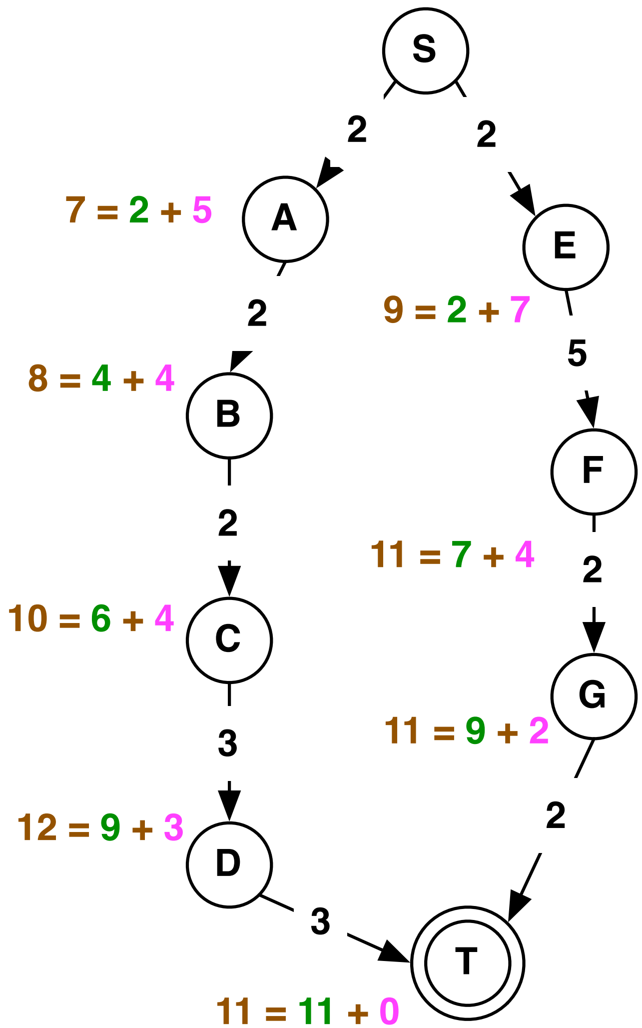
Forget expansion from A

A has backed up F value 12

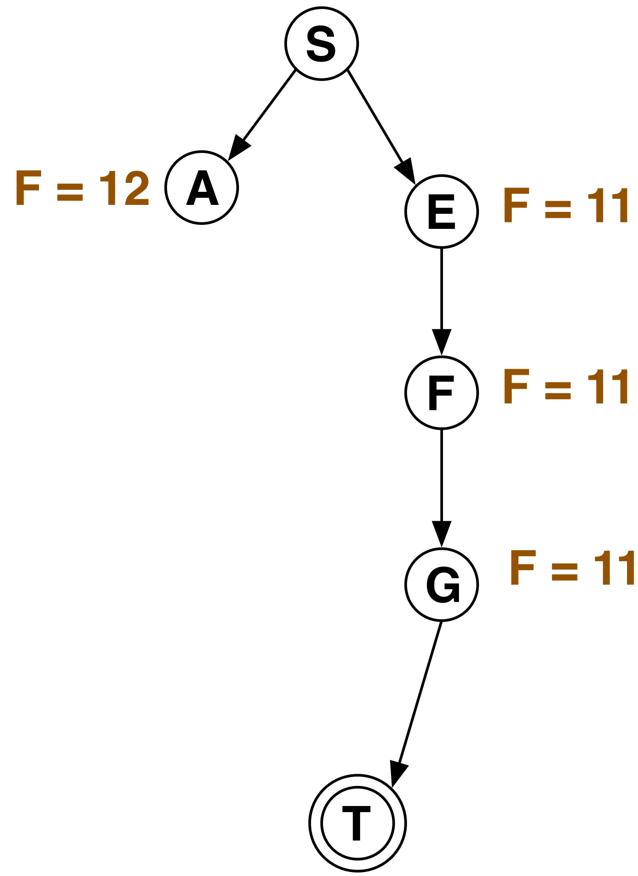
E is best to expand next

f(n) in mocha = g(n) in clover + h(n) in magenta

Fig 12.2 snapshots – 8



f(n) in mocha = g(n) in clover + h(n) in magenta



E is expanded with bound 12

Reach goal, search ends

Algorithm

function NewF (N, F(N), Bound)

- **if** F(N) > Bound **then** NewF := F(N)
- **else if** goal(N) then exit search with success
- **else if** N has no children then NewF := infinity – dead end
- **else for** each child N_k of N **do**
  - **if** f(N) < F(N) **then** $F(N_k)$:= max(F(N), $f(N_k)$)
  - **else** $F(N_k)$:= $f(N_k)$
  - sort children N_k in increasing order of F-value
  - **while** $F(N_1) \leq$ Bound and $F(N_1)$ < infinity **do**
    - Bound1 := min (Bound, F-value of sibling N_1)
    - $F(N_1)$:= NewF (N_1, $F(N_1)$, Bound1)
    - reorder nodes N_1, N_2 , … according to new $F(N_1)$
  - **end**
- **end**
- NewF := $F(N_1)$