CS 4260 and CS 5260
Vanderbilt University

Lecture on Planning under Uncertainty

This lecture assumes that you have

- Read Section 9 through 9.2, watched lecture on belief network inference, and read section 8.5 of ArtInt

ArtInt: Poole and Mackworth, Artificial Intelligence 2E
at http://artint.info/2e/html/ArtInt2e.html
to include slides at http://artint.info/2e/slides/ch09/

Douglas H. Fisher

Adapted from Poole and Mackworth, Artificial Intelligence 2E slides at http://artint.info/2e/slides/ch08/lect5.pdf

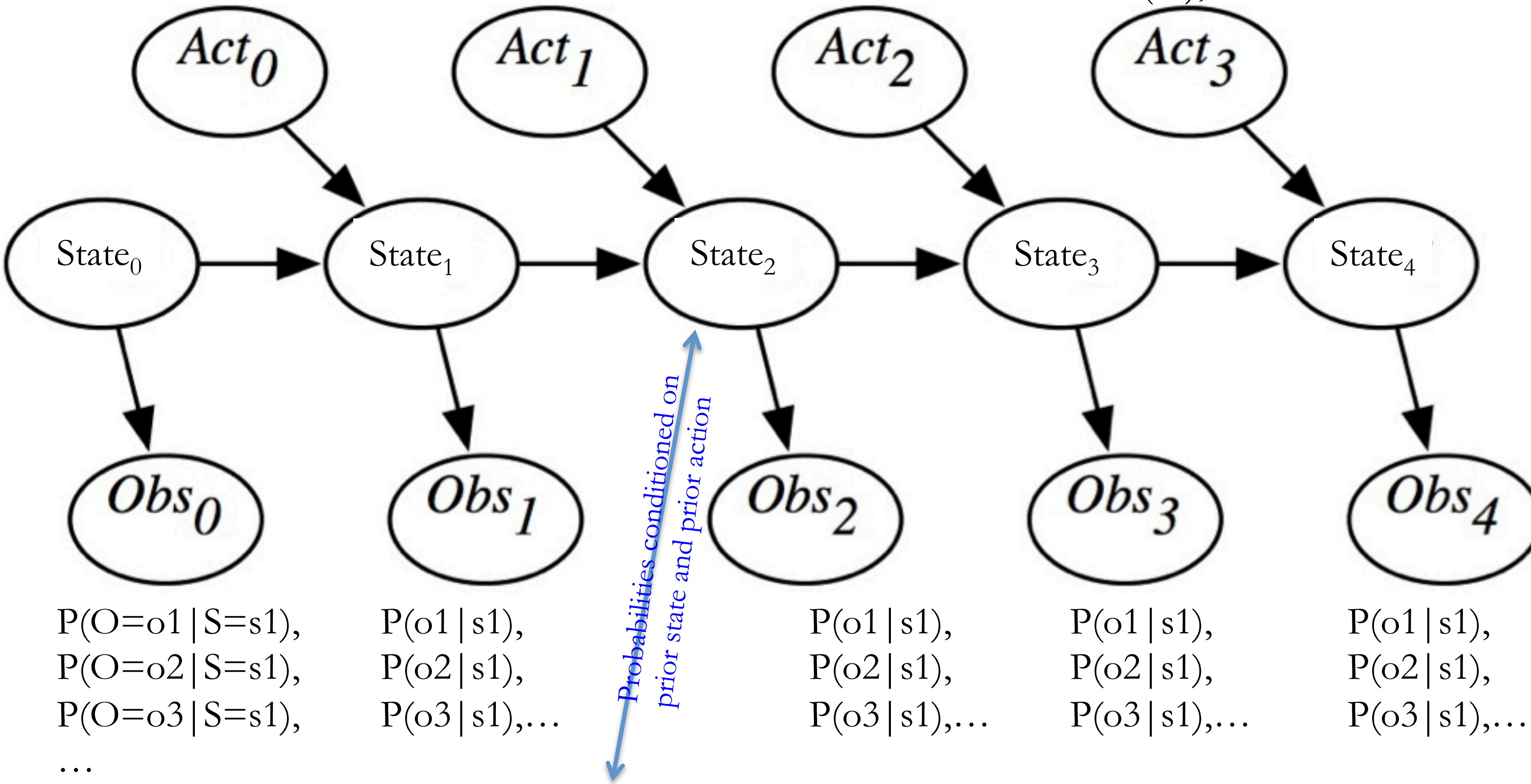
Recall Augmented HMMs

P(a1), P(a2), P(a3),…

P(a1), P(a2), P(a3),…

P(a1), P(a2), P(a3),…

P(a1), P(a2), P(a3),…



P(O=o1|S=s1),
P(O=o2|S=s1),
P(O=o3|S=s1),
…
P(O=oi|S=sk)

P(o1|s1),
P(o2|s1),
P(o3|s1),…

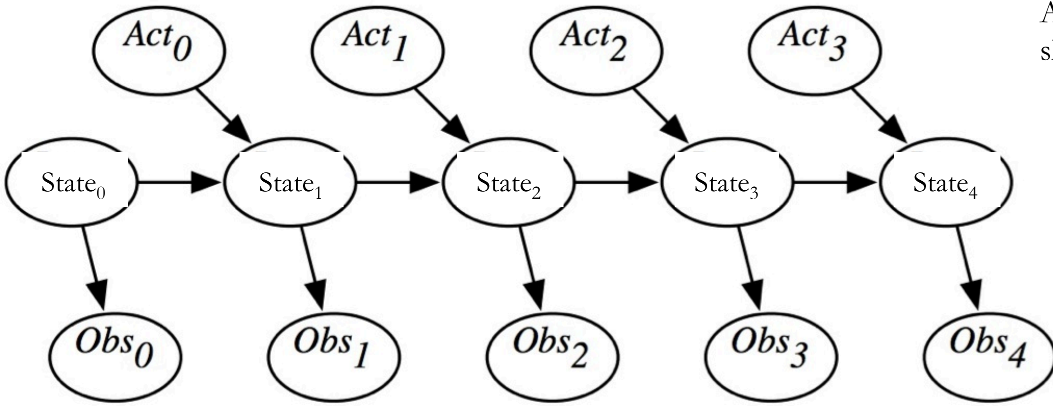
$P(S_2=s_k | S_1=s_j , A_1=a_i)$,

P(o1|s1),
P(o2|s1),
P(o3|s1),…

P(o1|s1),
P(o2|s1),
P(o3|s1),…

P(o1|s1),
P(o2|s1),
P(o3|s1),…

Douglas H. Fisher



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Recall filtering (with actions)
Slide 19 of MM and HMM lecture

$P(S_1 = s_k \mid O_0 = o_h, A_0 = a_i)$

$P(S_1 = s_? \mid O_0 = o_h, A_0 = a_i)$?

P(S_1 = < cs, rhc, swc, mw, rhm> | S_0 = < cs, ~rhc, swc, mw, rhm>, A_0=puc) = 0.95

(high probability because preconditions satisfied – robot in coffee shop and not already holding coffee – and consistent with Robot's mission)

P(S_1 = < lab, rhc, swc, mw, rhm> | S_0 = < lab, ~rhc, swc, mw, rhm>, A_0=puc) = 0.0

(zero probability because preconditions NOT satisfied – robot is not in coffee shop)

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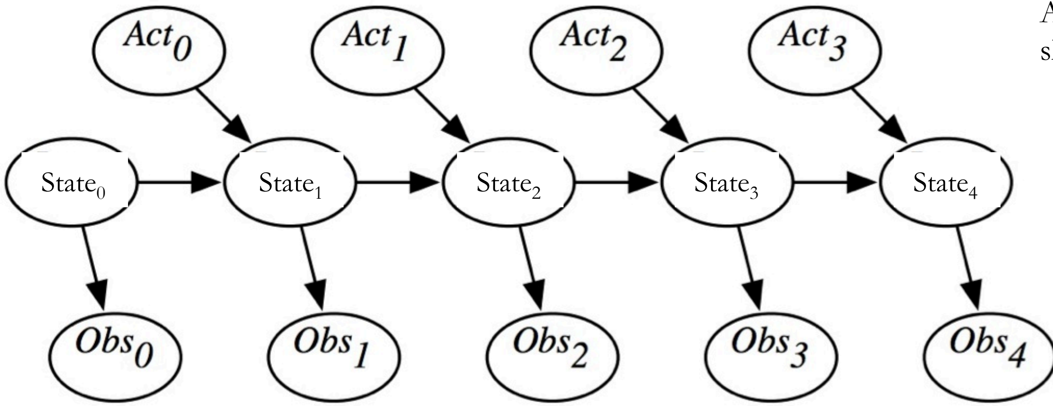

Recall filtering (with actions)
Slide 19 of MM and HMM lecture

$P(S_1 = s_k \mid O_0 = o_h, A_0 = a_i)$

$P(S_1 = s_? \mid O_0 = o_h, A_0 = a_i)$?

$= P(S_1 = s_k, O_0 = o_h, A_0 = a_i) / P(O_0 = o_h, A_0 = a_i)$

$= [\Sigma_{s'} P(S_1 = s_k, O_0 = o_h, A_0 = a_{i,} S_0 = s')] / P(O_0 = o_h, A_0 = a_i)$

$= [\Sigma_{s'} P(S_1 = s_k \mid O_0 = o_h, A_0 = a_{i,} S_0 = s') P(O_0 = o_h, A_0 = a_{i,} S_0 = s')]$
$/ P(O_0 = o_h, A_0 = a_i)$

$= [\Sigma_{s'} P(S_1 = s_k \mid A_0 = a_{i,} S_0 = s') P(O_0 = o_h \mid A_0 = a_{i,} S_0 = s') P(A_0 = a_{i,} S_0 = s')]$
$/ P(O_0 = o_h, A_0 = a_i)$

$= [\Sigma_{s'} P(S_1 = s_k \mid A_0 = a_{i,} S_0 = s') P(O_0 = o_h \mid S_0 = s') \cancel{P(A_0 = a_i)} P(S_0 = s')]$
$/ [\Sigma_{s'} P(O_0 = o_h \mid S_0 = s') P(S_0 = s') \cancel{P(A_0 = a_i)}]$

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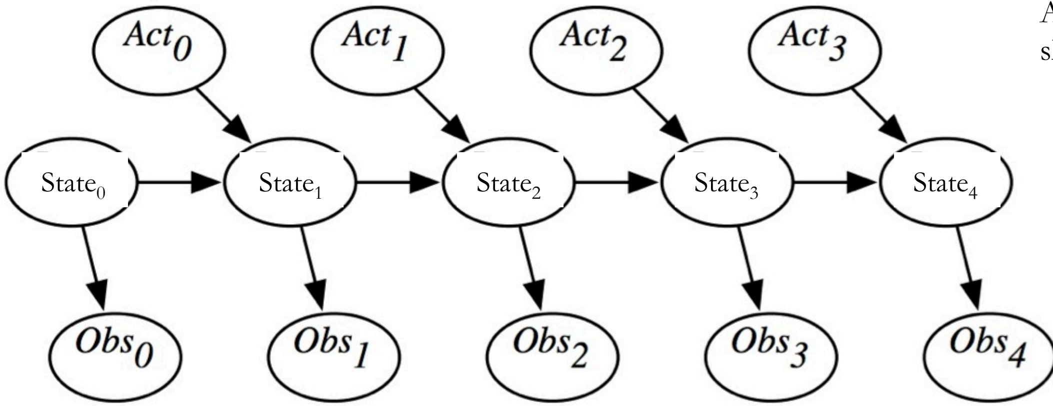
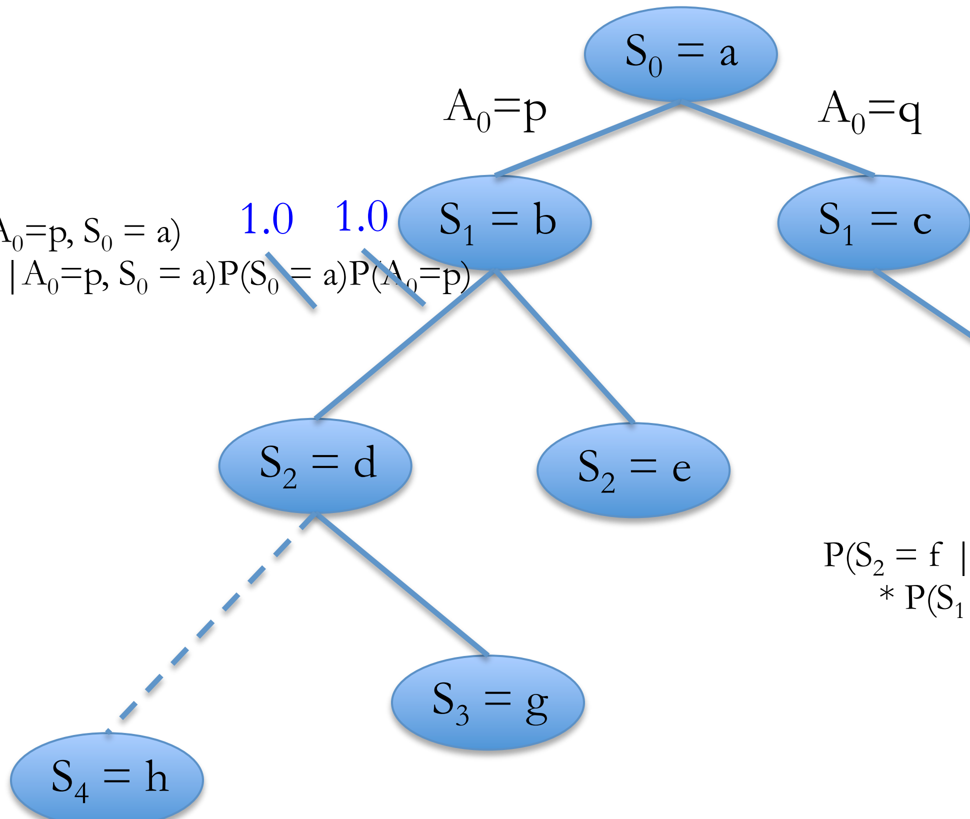


The augmented HMM
defines a search space
that is qualified by probabilities

Assuming action is taken with certainty

Assuming that the start State is known with certainty



$P(S_1 = c\ , A_0=q, S_0 = a)$
$= P(S_1 = c \mid A_0=q, S_0 = a)\cancelto{1.0}{P(S_0 = a)}\cancelto{1.0}{P(A_0=q)}$

$P(S_1 = b\ , A_0=p, S_0 = a)$
$= P(S_1 = b \mid A_0=p, S_0 = a)\cancelto{1.0}{P(S_0 = a)}\cancelto{1.0}{P(A_0=p)}$

$P(S_2 = f \mid A_1=r, S_1=c)$
$* P(S_1 = c \mid A_0=q, S_0 = a)\cancelto{1.0}{P(A1=r)}\ \cancelto{1.0}{P(S_0 = a)}\cancelto{1.0}{P(A_0=q)}$

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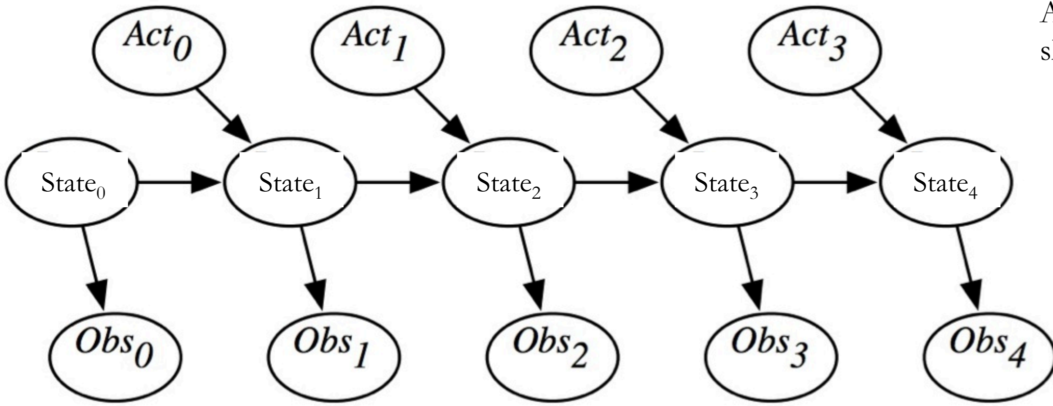
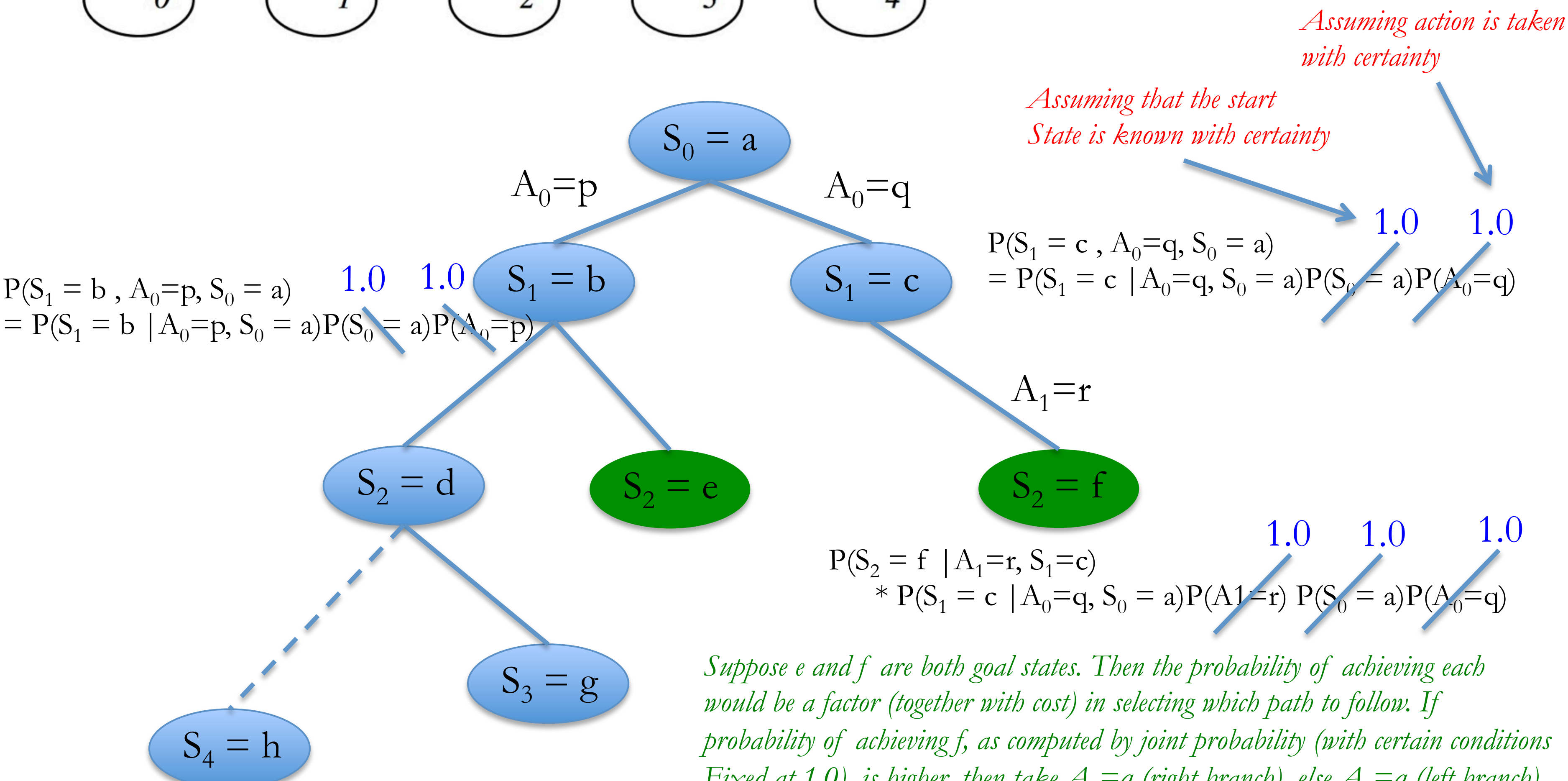


The augmented HMM defines a search space that is qualified by probabilities



Suppose e and f are both goal states. Then the probability of achieving each would be a factor (together with cost) in selecting which path to follow. If probability of achieving f, as computed by joint probability (with certain conditions Fixed at 1.0), is higher, then take A_0=q (right branch), else A_0=q (left branch)

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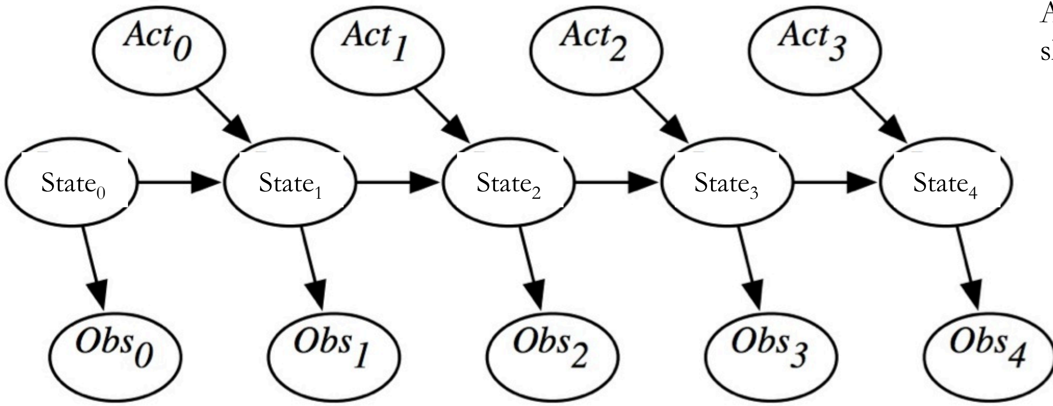

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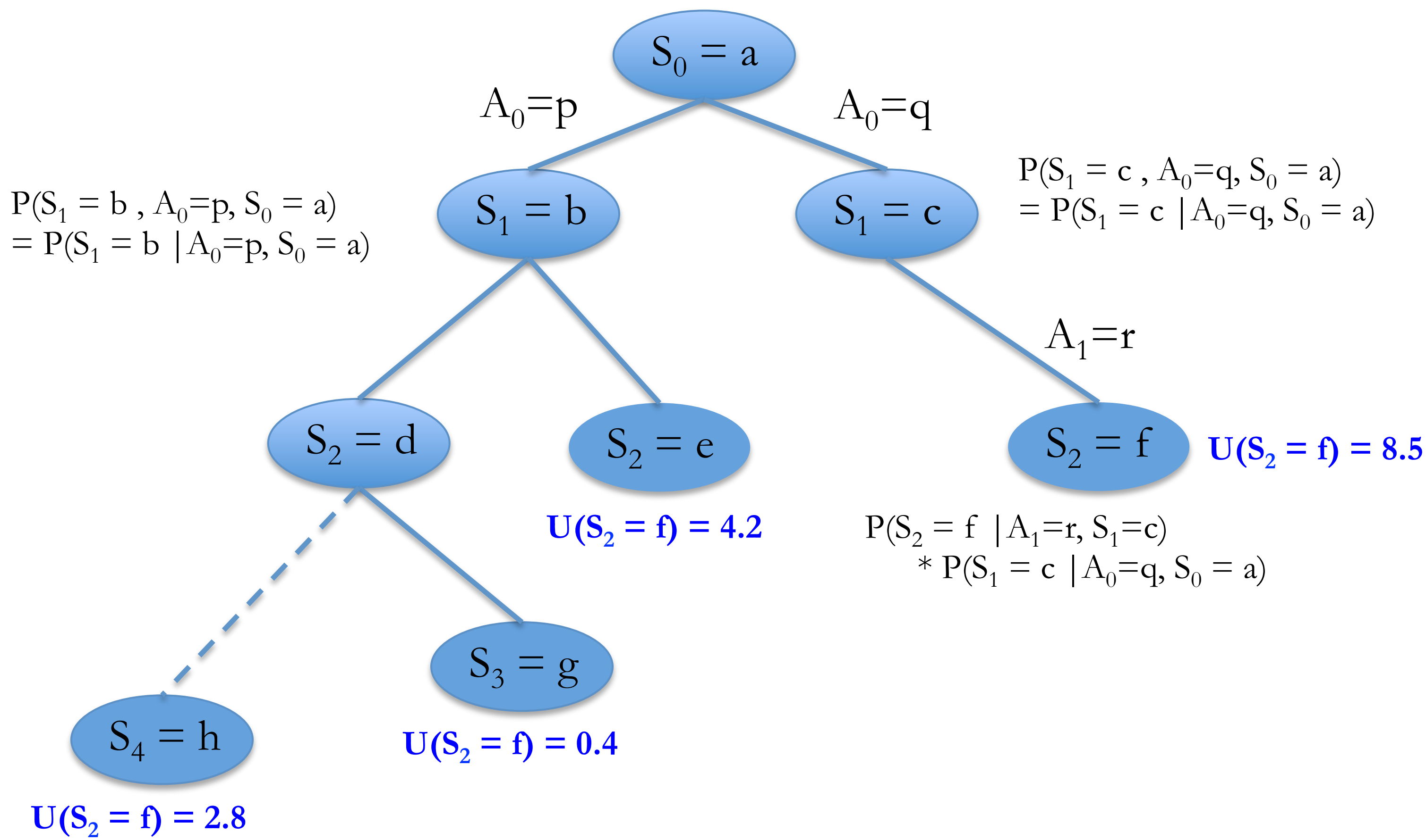
It is often the case, that states have associated utilities, U, rather than being goals (or not)



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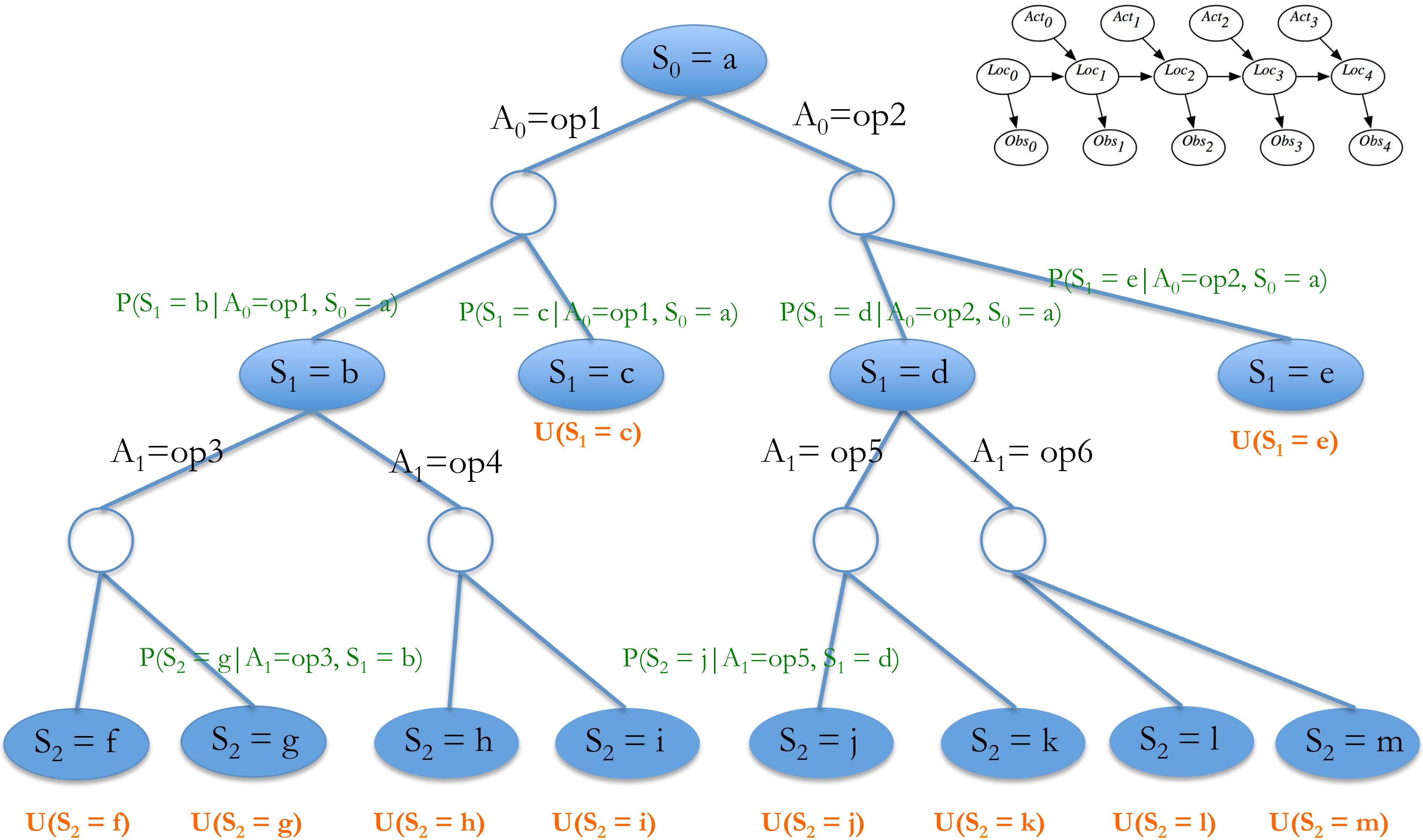
Need more representational power to represent uncertainty in operator effects



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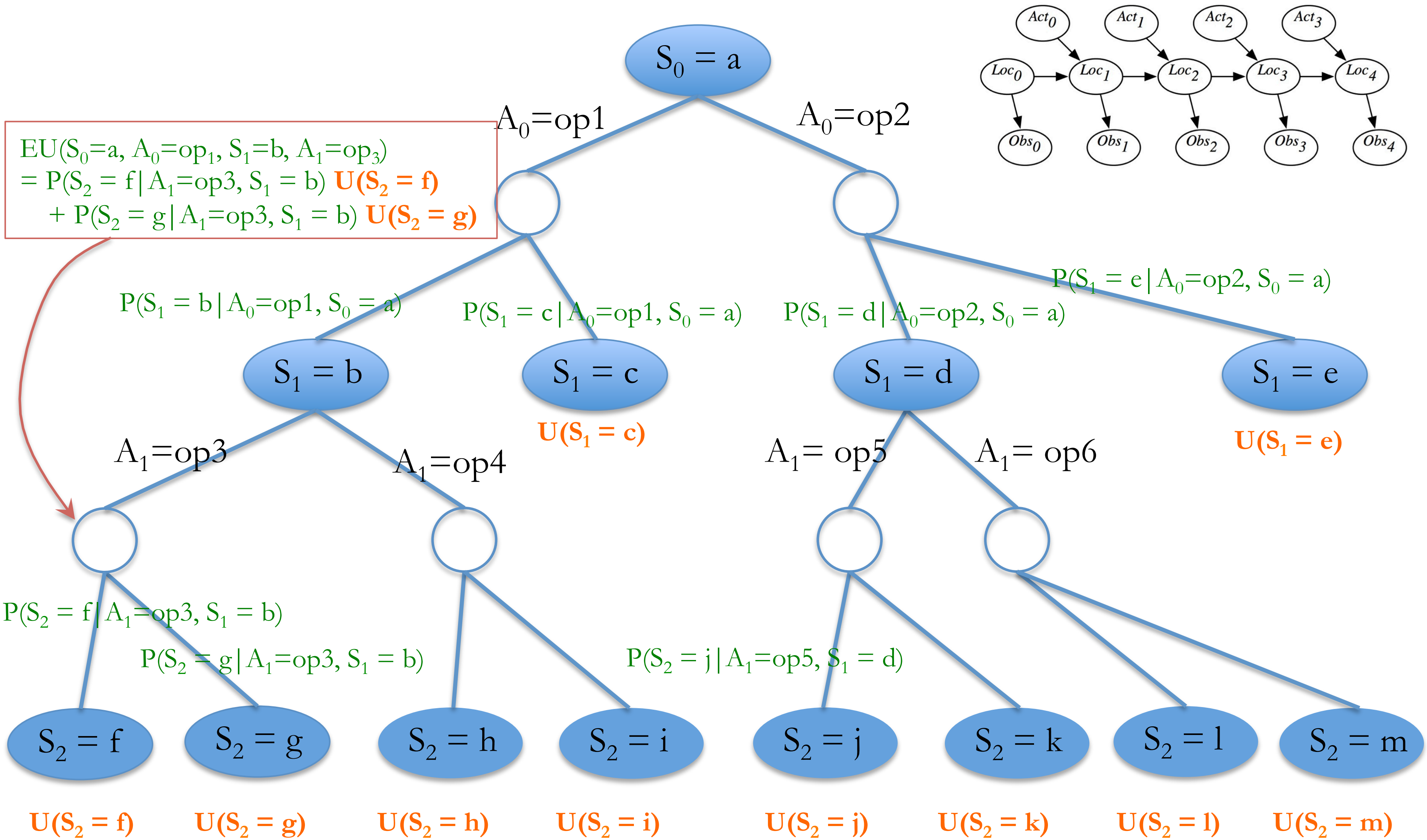

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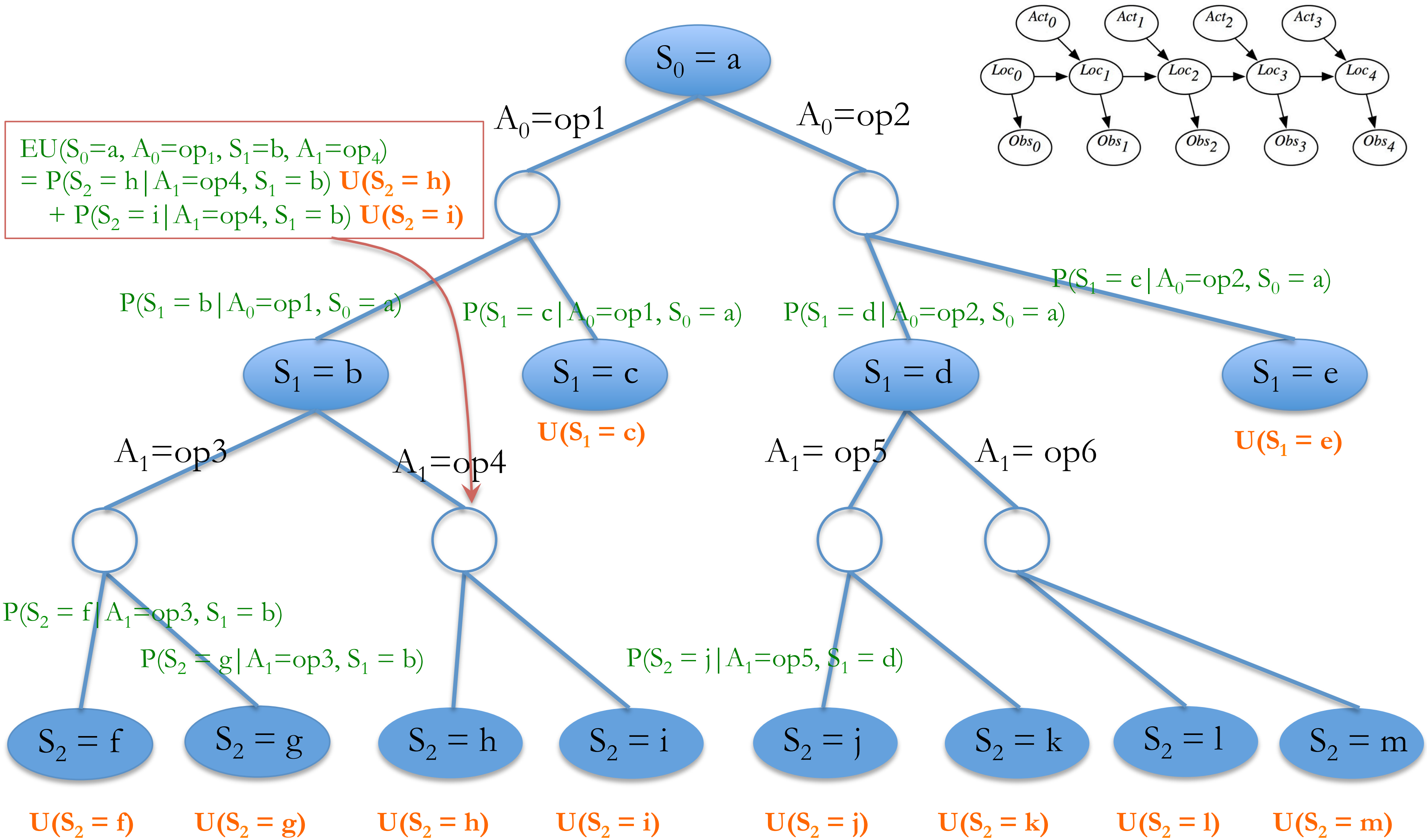

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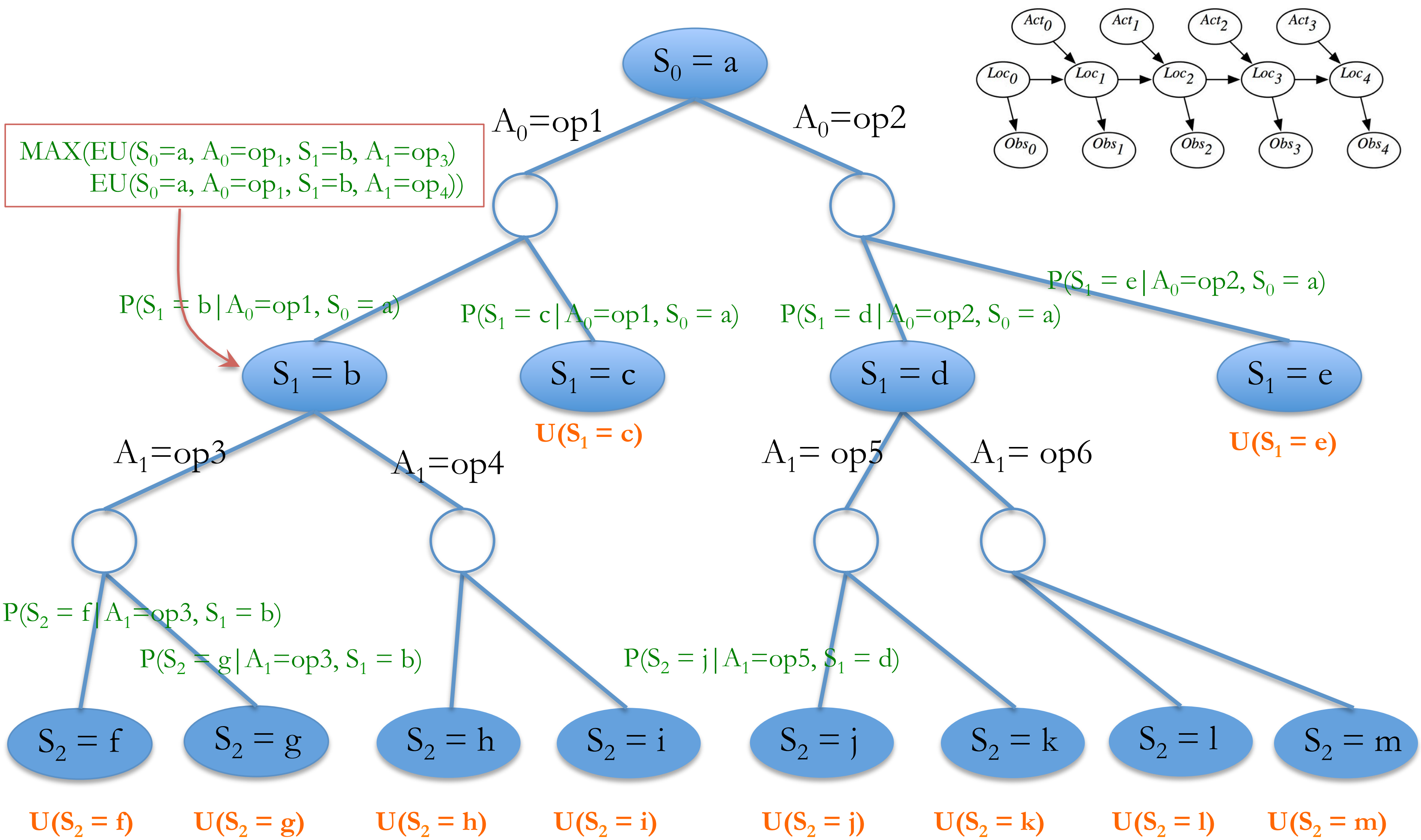
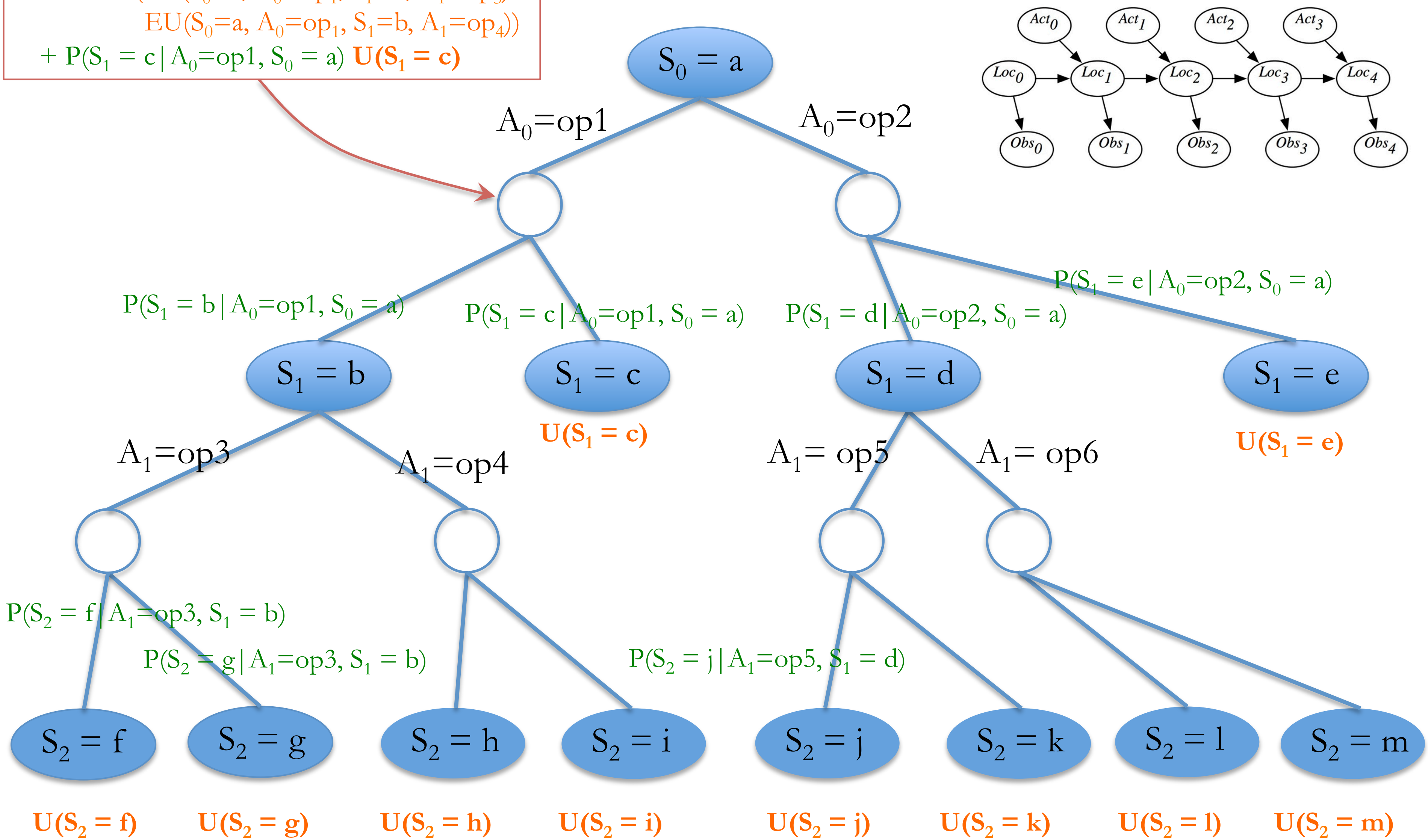


$EU(S_0=a, A_0=op_1)$
$= P(S_1 = b \mid A_0=op1, S_0 = a)$
$\quad * \; MAX(EU(S_0=a, A_0=op_1, S_1=b, A_1=op_3)$
$\qquad\qquad EU(S_0=a, A_0=op_1, S_1=b, A_1=op_4))$
$\quad + P(S_1 = c \mid A_0=op1, S_0 = a)$ **$U(S_1 = c)$**



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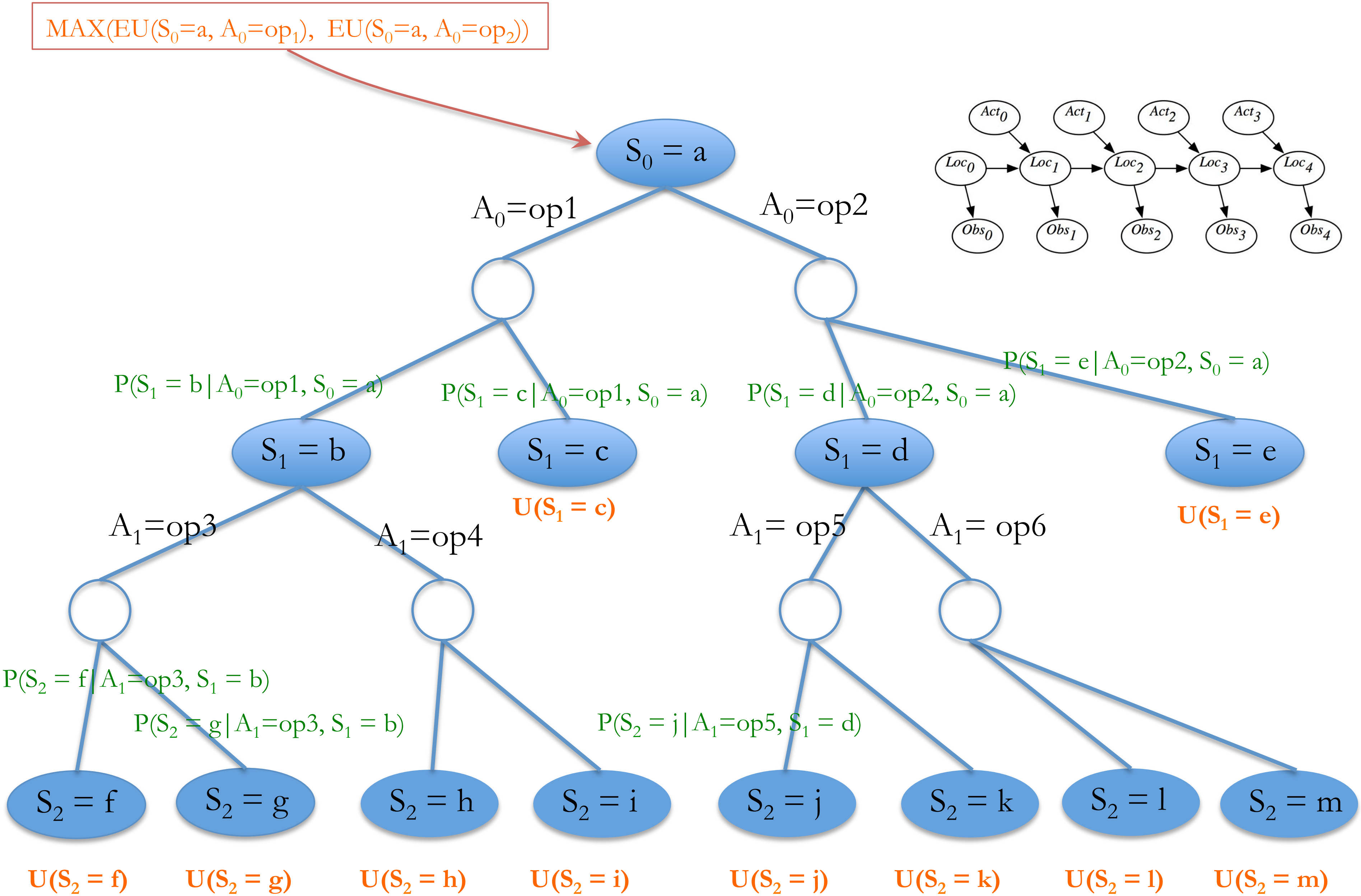

MAX(EU(S0=a, A0=op1), EU(S0=a, A0=op2))
Act0
Act1
Act2
Act3
Loc0
Loc1
Loc2
Loc3
Loc4
Obs0
Obs1
Obs2
Obs3
Obs4
S0 = a
A0=op1
A0=op2
P(S1 = b | A0=op1, S0 = a)
P(S1 = c | A0=op1, S0 = a)
P(S1 = d | A0=op2, S0 = a)
P(S1 = e | A0=op2, S0 = a)
S1 = b
S1 = c
S1 = d
S1 = e
U(S1 = c)
U(S1 = e)
A1=op3
A1=op4
A1= op5
A1= op6
P(S2 = f | A1=op3, S1 = b)
P(S2 = g | A1=op3, S1 = b)
P(S2 = j | A1=op5, S1 = d)
S2 = f
S2 = g
S2 = h
S2 = i
S2 = j
S2 = k
S2 = l
S2 = m
U(S2 = f)
U(S2 = g)
U(S2 = h)
U(S2 = i)
U(S2 = j)
U(S2 = k)
U(S2 = l)
U(S2 = m)