FROM E. RICH, (AI).

the quantity of water in the 3-gallon jug. The start state is (0, 0). The goal state is (2, n) for any value of n (since the problem does not specify how many gallons need to be in the 3-gallon jug).

```
1 (X,Y | X<4) → (4,Y)          Fill the 4-gallon jug
2 (X,Y | Y<3) → (X,3)          Fill the 3-gallon jug
3 (X,Y | X>0) → (X-D,Y)        Pour some water out of
                                       the 4-gallon jug
4 (X,Y | Y>0) → (X,Y-D)        Pour some water out of
                                       the 3-gallon jug
5 (X,Y | X>0) → (0,Y)          Empty the 4-gallon jug
                                       on the ground
6 (X,Y | Y>0) → (X,0)          Empty the 3-gallon jug
                                       on the ground
7 (X,Y | X+Y>=4 ∧ Y>0) →       Pour water from the
      (4,Y-(4-X))                     3-gallon jug into the
                                      4-gallon jug until the
                                      4-gallon jug is full
8 (X,Y | X+Y>=3 ∧ X>0) →       Pour water from the
      (X-(3-Y),3)                     4-gallon jug into the
                                      3-gallon jug until the
                                      3-gallon jug is full
9 (X,Y | X+Y<=4 ∧ Y>0) →       Pour all the water
      (X+Y,0)                          from the 3-gallon jug
                                       into the 4-gallon jug
10 (X,Y | X+Y<=3 ∧ X>0) →      Pour all the water
      (0,X+Y)                          from the 4-gallon jug
                                       into the 3-gallon jug
```

Figure 2–3: Production Rules for the Water Jug Problem

The operators to be used to solve the problem can be described as shown in Figure 2–3. As in the chess problem, they are represented as rules whose left sides are matched against the current state and whose right sides describe the new state that results from applying the rule. Notice that in order to describe the operators completely, it was necessary to make explicit some assumptions not mentioned in the problem statement. We have assumed that we can fill a jug from the pump, that we can pour water out of a jug onto the ground, that we can pour water from one jug to another, and that there are no other measuring devices available. Additional assumptions such as these are almost always required when converting from a typical problem statement given in English to a formal representation of the problem suitable for use by a program.

To solve the water jug problem, all we need, in addition to the problem description given above, is a control structure that loops through a simple cycle in which some rule whose left side matches the current state is chosen, the appropriate change to the state is made as described in the corresponding right side, and the resulting state is checked to see if it corresponds to a goal state. As long

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as it does not, the cycle continues. Clearly the speed with which the problem gets solved depends on the mechanism that is used to select the next operation to perform. In Chapter 3, several ways of making that selection will be discussed. This corresponds to the situation in chess in which any choice from among the applicable operators will lead to a legal game, but only some choices will lead to a winning one.

Gallons in 4-Gallon Jug	Gallons in 3-Gallon Jug	Rule Applied
0	0	
		2
0	3	
		9
3	0	
		2
3	3	
		7
4	2	
		5
0	2	
		9
2	0	

Figure 2–4: One Solution to the Water Jug Problem

For the water jug problem, as with many others, there are several sequences of operators that will solve the problem. One such sequence is shown in Figure 2–4.

Often, a problem contains the explicit or implied statement that the shortest (or cheapest) such sequence be found. If present, this requirement will have a significant effect on the choice of an appropriate mechanism to guide the search for a solution. This issue will be discussed in Section 2.2.

A serious issue that often arises in converting an informal problem statement into a formal problem description and then solving it by finding an appropriate set of rules to apply is exemplified by rules 3 and 4 in Figure 2–3. Should they or should they not be included in the list of available operators? Emptying an unmeasured amount of water onto the ground is certainly allowed by the problem statement. But a superficial preliminary analysis of the problem makes it clear that doing so will never get us closer to a solution. In practical situations, such rules would normally be omitted. In other situations, in which the reason for solving the problem is to demonstrate the utility of some proposed way of reasoning (choosing which rules to apply), it may be important to include such rules lest the criticism be levied that the program itself displayed no intelligence--that the solution was programmed in to it. In still other situations, possibly ineffectual rules may be included in order to maintain generality. At