THE CAR ASSEMBLY PROBLEM WARREN

The problem is formulated in terms of the ...
objects, ~~data~~ facts and actions :—

OBJECTS

numbers, $N = \langle 1, 2, \text{etc} \rangle$
directions, $D = \langle \text{left, right} \rangle$
wheels, $W = \langle \text{wheel } N \rangle$
axles, $A = \langle \text{axle } N \rangle$
ends of axles, $E = \langle D \text{ end of } A \rangle$
holes, $H = \langle \text{hole } N \rangle$
vice, $V = \langle \text{vice} \rangle$

FACTS

STATIC: D   is opposite of   D
DYNAMIC   W   is attached to   E
     A   is thru   H
     E   points   D
     Carbody is blocked to   D
     Carbody is unblocked to   D
     W + A   is clamped
     W + A + H + V   is free
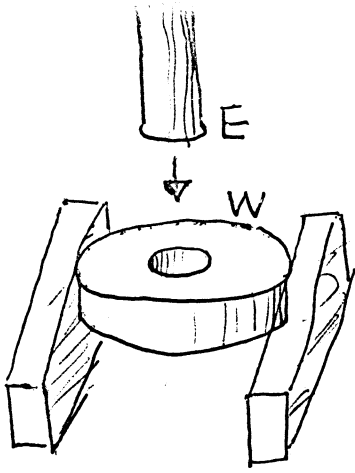
ACTIONS

insert E into W
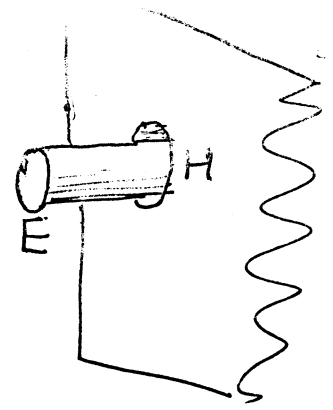push W from D to D onto E in H
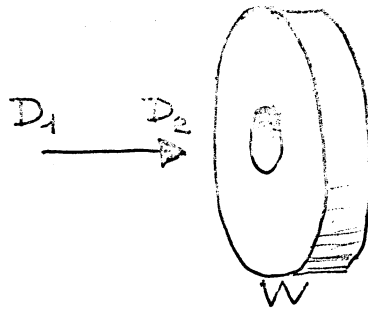slide E into H from D
block carbody to D
unblock carbody to D
clamp W
unclamp W + A &c
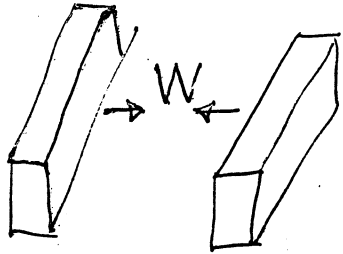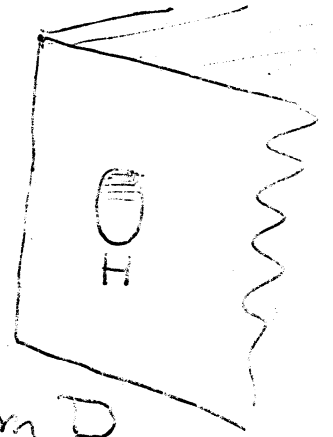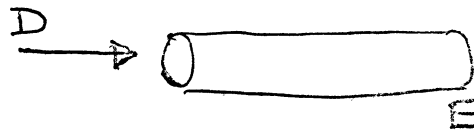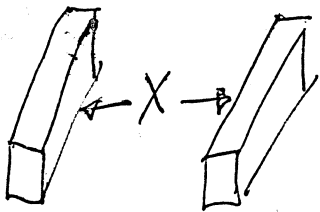
insert E into W

Push W from D_1 to D_2 onto E in H

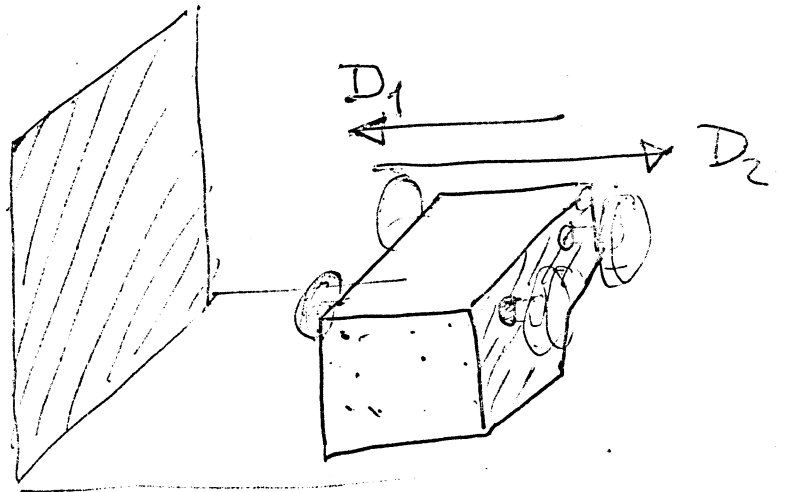clamp W

Slide E into H from D

unclamp X

block car body to D_1

unblock car body to D_2

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*** CAR ASSEMBLY.

         INSERT(GD,4).
       +PUSH(GD,4).
       +SLIDE(GD,4).
       +CLAMP(GD,4).
       +UNCLAMP(GD,4).
       +BLOCKCARBODYTO(GD,4).
       +UNBLOCKCARBODYTO(GD,4).

       +CARBODYISUNBLOCKEDTO(GD,4).
       +CARBODYISBLOCKEDTO(GD,4).

       +ISFREE(DG,4).
       +ISCLAMPED(DG,4).

       +ISTHRU(DG,4).
       +POINTS(DG,4).
       +ISOPPOSITEOF(DG,4).
       +ISATTACHEDTO(DG,4).

       +INTO(DG,5).
       +FROM(DG,5).
       +TO(DG,5).
       +ONTO(DG,5).
       +IN(DG,5).

       +ENDOF(DG,6).

       +WHEEL(GD,7).
       +AXLE(GD,7).
       +HOLE(GD,7).


       +ADD( *W ISATTACHEDTO *E, INSERT *E INTO *W ).
       +ADD( *W ISATTACHEDTO *E, PUSH *W FROM *D1 TO *D2 ONTO *E IN *H ).
       +ADD( *A ISTHRU *H, SLIDE *D1 ENDOF *A INTO *H FROM *D2 ).
       +ADD( WHEEL *W ISCLAMPED, CLAMP WHEEL *W ).
       +ADD( AXLE *A ISCLAMPED, INSERT *D ENDOF AXLE *A INTO *W ).
       +ADD( WHEEL *W ISFREE, UNCLAMP WHEEL *W ).
       +ADD( AXLE *A ISFREE, UNCLAMP AXLE *A ).
       +ADD( VICE ISFREE, UNCLAMP *X ).
       +ADD( CARBODYISBLOCKEDTO *D, BLOCKCARBODYTO *D ).
       +ADD( CARBODYISUNBLOCKEDTO *D, UNBLOCKCARBODYTO *D ).
       +ADD( *D1 ENDOF *A POINTS *D, SLIDE *D1 ENDOF *A INTO *H FROM *D2 )
          -ALWAYS( *D ISOPPOSITEOF *D2 ).
       +ADD( *D ENDOF *A POINTS *D2, SLIDE *D1 ENDOF *A INTO *H FROM *D2 )
          -ALWAYS( *D ISOPPOSITEOF *D1 ).

       +CAN( INSERT *D ENDOF AXLE *A INTO WHEEL *W,
               AXLE *A ISFREE &
               *D ENDOF AXLE *A ISFREE &
               WHEEL *W ISCLAMPED ).
       +CAN( PUSH WHEEL *W FROM *D1 TO *D2 ONTO *D ENDOF AXLE *A IN HOLE *H,
               WHEEL *W ISFREE &
               *D ENDOF AXLE *A ISFREE &
               AXLE *A ISTHRU HOLE *H &
               *D ENDOF AXLE *A POINTS *D1 &
               CARBODYISUNBLOCKEDTO *D1 &
               *D2 ISOPPOSITEOF *D1 &
               CARBODYISBLOCKEDTO *D2 ).
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+CAN( SLIDE *D1 ENDOF AXLE *A INTO HOLE *H FROM *D2,
          AXLE *A ISFREE &
          *D1 ENDOF AXLE *A ISFREE &
          HOLE *H ISFREE &
          CARBODYISUNBLOCKEDTO *D2 ).
+CAN( CLAMP WHEEL *W,
          WHEEL *W ISFREE &
          VICE ISFREE ).
+CAN( UNCLAMP *X,
          *X ISCLAMPED ).
+CAN( BLOCKCARBODYTO *D, TRUE ).
+CAN( UNBLOCKCARBODYTO *D, TRUE ).

+DEL( *X ISFREE, *U ) -ADD( *X ISCLAMPED, *U ).
+DEL( *X ISFREE, *U ) -ADD( *X ISATTACHEDTO *Z, *U ).
+DEL( *X ISFREE, *U ) -ADD( *Z ISATTACHEDTO *X, *U ).
+DEL( *A ISFREE, SLIDE *D1 ENDOF *A INTO *H FROM *D2 ).
+DEL( *H ISFREE, SLIDE *E INTO *H FROM *D2 ).
+DEL( VICE ISFREE, CLAMP *W ).
+DEL( CARBODYISUNBLOCKEDTO *D, BLOCKCARBODYTO *D ).
+DEL( CARBODYISBLOCKEDTO *D, UNBLOCKCARBODYTO *D ).
+DEL( *Z ISCLAMPED, UNCLAMP *X ).
+DEL( *W ISCLAMPED, INSERT *E INTO *W ).

+IMPOSS( AXLE *A ISFREE & AXLE *A ISTHRU HOLE *H ).
+IMPOSS( *D ENDOF *A ISFREE & *W ISATTACHEDTO *D ENDOF *A ).
+IMPOSS( WHEEL *W ISFREE & WHEEL *W ISATTACHEDTO *E ).
+IMPOSS( WHEEL *W ISFREE & WHEEL *W ISCLAMPED ).
+IMPOSS( HOLE *H ISFREE & *A ISTHRU HOLE *H ).
+IMPOSS( AXLE *A ISFREE & AXLE *A ISCLAMPED ).
+IMPOSS( VICE ISFREE & *X ISCLAMPED ).
+IMPOSS( CARBODYISBLOCKEDTO *D & CARBODYISUNBLOCKEDTO *D ).

+ALWAYS( TRUE ).
+ALWAYS( LEFT ISOPPOSITEOF RIGHT ).
+ALWAYS( RIGHT ISOPPOSITEOF LEFT ).

+GIVEN(START, WHEEL *W ISFREE ) -ELEM(*W,1&2&3&4).
+GIVEN(START, AXLE *A ISFREE ) -ELEM(*A,1&2).
+GIVEN(START, *D ENDOF AXLE *A ISFREE )
   -ELEM(*D,LEFT&RIGHT)-ELEM(*A,1&2).
+GIVEN(START, HOLE *H ISFREE ) -ELEM(*H,1&2).
+GIVEN(START, VICE ISFREE ).
+GIVEN(START, CARBODYISUNBLOCKEDTO *D ) -ELEM(*D,LEFT&RIGHT).

+GIVEN(MIDDLE, WHEEL *W ISFREE ) -ELEM(*W,2&3&4).
+GIVEN(MIDDLE, WHEEL 1 ISATTACHEDTO LEFT ENDOF AXLE 1 ).
+GIVEN(MIDDLE, AXLE *N ISTHRU HOLE *N ) -ELEM(*N,1&2).
+GIVEN(MIDDLE, *D ENDOF AXLE *A POINTS *D )
   -ELEM(*D,LEFT&RIGHT)-ELEM(*A,1&2).
+GIVEN(MIDDLE, RIGHT ENDOF AXLE *A ISFREE ) -ELEM(*A,1&2).
+GIVEN(MIDDLE, LEFT ENDOF AXLE 2 ISFREE ).
+GIVEN(MIDDLE, VICE ISFREE ).
+GIVEN(MIDDLE, CARBODYISUNBLOCKEDTO *D ) -ELEM(*D,LEFT&RIGHT).

+GOAL(*T)-PLANS( AXLE *A1 ISTHRU HOLE 1 &
                 AXLE *A2 ISTHRU HOLE 2 &
                 WHEEL *W1 ISATTACHEDTO LEFT ENDOF AXLE *A1 &
                 WHEEL *W2 ISATTACHEDTO LEFT ENDOF AXLE *A2 &
                 WHEEL *W3 ISATTACHEDTO RIGHT ENDOF AXLE *A1 &
                 WHEEL *W4 ISATTACHEDTO RIGHT ENDOF AXLE *A2, *T ).

+FIN.
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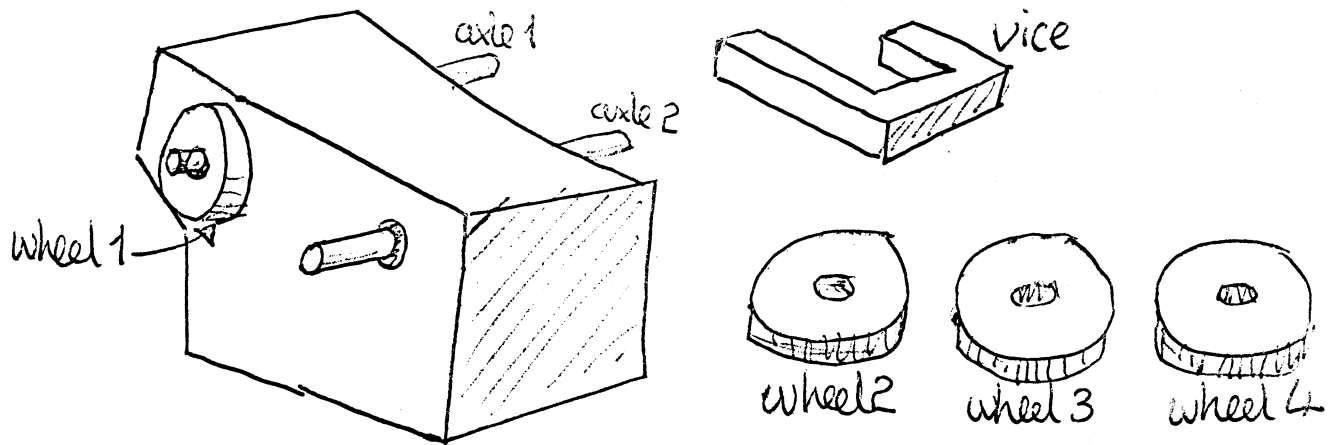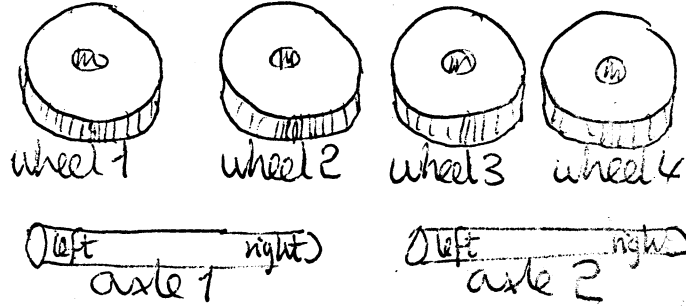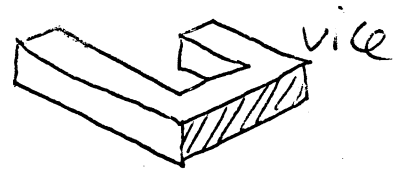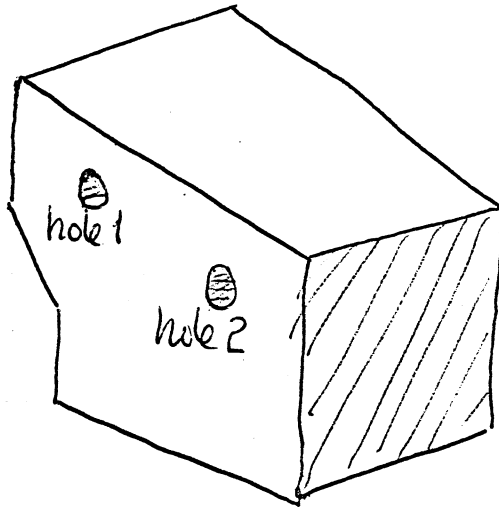
Problem I

- goal (middle).   [assemble car from intermediate
state 'middle' pictured above]

Ans: block car body to right;
push wheel 2 from left to right onto left end of axle 2
in hole 2;

unblock car body to right;
block car body to left;
push wheel 3 from right to left onto right end of
axle 1 in hole 1;
push wheel 4 from right to left onto right end of
axle 2 in hole 2

Time: 2 min 40 sec
[1 min 59 sec]

Problem II

- goal (start)   [assemble car from initial state 'start' pictured above]

Ans: slide left end of axle 1 into hole 1 from left;
slide left end of axle 2 into hole 2 from left;
block car body to left;
push wheel 1 from right to left onto left end of
    axle 1 in hole 1;
push wheel 2 from right to left onto left end of
    axle 2 in hole 2;
unblock car body to left;
block car body to right;
push wheel 3 from left to right onto right
    end of axle 1 in hole 1;
push wheel 4 from left to right onto right
    end of axle 2 in hole 2

(A novel
solution
for
Freddy)

Time: 6 min 18 sec.
       [4 min 41 sec]

Problem III (A variant of problem II.)

- plans (
  wheel W_1 is attached to left end of axle A_1 &
  wheel W_2 is attached to right end of axle A_2 &
  axle A_1 is thru hole 1 &
  axle A_2 is thru hole 2 &
  wheel W_3 is attached to right end of axle A_3 &
  wheel W_4 is attached to left end of axle A_2,
  start).

Ans: clamp wheel 1;
       insert left end of axle 1 into wheel 1;
       unclamp axle 1;
       clamp wheel 2;
       insert right end of axle 2 into wheel 2;
       slide right end of axle 1 into hole 1 from left;
       unclamp axle 2;
       slide left end of axle 2 into hole 2 from left;
       block car body to left;
       push wheel 3 from right to left onto right end of
                     axle 1 in hole 1;
       push wheel 4 from right to left onto left end
                     axle 2 in hole 2.

(Actual
method
used by
Freddy)

Time: 5 min 23 sec.