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1  ---------- MODULE XJupiter ----------
   Specification of the Jupiter protocol described in CSCW'2014 by Yi Xu, Chengzheng Sun, and
   Mo Li. We call it XJupiter, with 'X' for "Xu".
7  EXTENDS StateSpace
8  ----------
9  VARIABLES
       The 2D state spaces (2ss, for short). Each client maintains one 2D state space. The server
       maintains n 2D state spaces, one for each client.
15     c2ss,     c2ss[c]: the 2D state space at client c ∈ Client
16     s2ss      s2ss[c]: the 2D state space maintained by the Server for client c ∈ Client
18 vars ≜ ⟨intVars, ctxVars, c2ss, s2ss⟩
19 ----------
20 TypeOK ≜
21     ∧  TypeOKInt
22     ∧  TypeOKCtx
23     ∧  Comm(Cop)!TypeOK
24     ∧  ∀ c ∈ Client : IsSS(c2ss[c]) ∧ IsSS(s2ss[c])
25 ----------
26 Init ≜
27     ∧ InitInt
28     ∧ InitCtx
29     ∧ Comm(Cop)!Init
30     ∧ c2ss = [c ∈ Client ↦ EmptySS]
31     ∧ s2ss = [c ∈ Client ↦ EmptySS]
32 ----------
   xForm: iteratively transform cop with a path through the 2D state space ss at some client.
37 xForm(cop, ss, current) ≜
38     LET u ≜ Locate(cop, ss)
39         v ≜ u ∪ {cop.oid}
40         RECURSIVE xFormHelper(_, _, _, _)
41          'h' stands for "helper"; xss: eXtra ss created during transformation
42         xFormHelper(uh, vh, coph, xss) ≜
43             IF uh = current
44              THEN ⟨xss, coph⟩
45              ELSE LET e ≜ CHOOSE e ∈ ss.edge : e.from = uh ∧ ClientOf(e.cop) ≠ ClientOf(cop)
46                       uprime ≜ e.to
47                       copprime ≜ e.cop
48                       coph2copprime ≜ COT(coph, copprime)
49                       copprime2coph ≜ COT(copprime, coph)
50                        vprime ≜ vh ∪ {copprime.oid}
51                   IN   xFormHelper(uprime, vprime, coph2copprime,
52                           [node ↦ xss.node ∪ {vprime},
53                            edge ↦ xss.edge ∪ {[from ↦ vh, to ↦ vprime, cop ↦ copprime2coph],
54                                               [from ↦ uprime, to ↦ vprime, cop ↦ coph2copprime]}])
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55      IN   xFormHelper(u, v, cop, [node ↦ {v}, edge ↦ {[from ↦ u, to ↦ v, cop ↦ cop]}])
56 ├──────────────────────────────────────────────────────────────────────────────┤
   Client c ∈ Client perform operation cop.
60  ClientPerform(cop, c) ≜
61      LET xform ≜ xForm(cop, c2ss[c], ds[c])   xform: ⟨xss, xcop⟩
62          xss   ≜ xform[1]
63          xcop  ≜ xform[2]
64      IN  ∧ c2ss' = [c2ss EXCEPT ![c] = @ ⊕ xss]
65          ∧ state' = [state EXCEPT ![c] = Apply(xcop.op, @)]
   Client c ∈ Client generates an operation op.
69  DoOp(c, op)  ≜
70        LET cop ≜ [op ↦ op, oid ↦ [c ↦ c, seq ↦ cseq'[c]], ctx ↦ ds[c]]
71            IN  ∧ ClientPerform(cop, c)
72                ∧ UpdateDS(c, cop)
73                ∧ Comm(Cop)!CSend(cop)

75  DoIns(c) ≜
76      ∃ ins ∈ {op ∈ Ins : op.pos ∈ 1 .. (Len(state[c]) + 1) ∧ op.ch ∈ chins ∧ op.pr = Priority[c]} :
77          ∧ DoOp(c, ins)
78          ∧ chins' = chins \ {ins.ch}   We assume that all inserted elements are unique.

80  DoDel(c) ≜
81      ∃ del ∈ {op ∈ Del : op.pos ∈ 1 .. Len(state[c])} :
82          ∧ DoOp(c, del)
83          ∧ UNCHANGED chins

85  Do(c) ≜
86        ∧ DoCtx(c)
87        ∧ ∨ DoIns(c)
88          ∨ DoDel(c)
89        ∧ UNCHANGED s2ss
   Client c ∈ Client receives a message from the Server.
93  Rev(c) ≜
94        ∧ Comm(Cop)!CRev(c)
95        ∧ LET cop ≜ Head(cincoming[c])   the received (transformed) operation
96            IN  ClientPerform(cop, c)
97        ∧ RevCtx(c)
98        ∧ UNCHANGED ⟨chins, s2ss⟩
99 ├──────────────────────────────────────────────────────────────────────────────┤
   The Server performs operation cop.
103 ServerPerform(cop) ≜
104     LET c ≜ ClientOf(cop)
105       scur ≜ ds[Server]
106     xform ≜ xForm(cop, s2ss[c], scur)   xform: ⟨xss, xcop⟩
107       xss ≜ xform[1]
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```
108       xcop  ≜  xform[2]
109       xcur  ≜  scur ∪ {cop.oid}
110     IN    ∧ s2ss' = [cl ∈ Client ↦
111                        IF cl = c
112                         THEN s2ss[cl] ⊕ xss
113                         ELSE s2ss[cl] ⊕ [node ↦ {xcur},
114                           edge ↦ {[from ↦ scur, to ↦ xcur, cop ↦ xcop]}]
115                      ]
116           ∧ state' = [state EXCEPT ![Server] = Apply(xcop.op, @)]
117           ∧ Comm(Cop)!SSendSame(c, xcop)   broadcast the transformed operation
```

The *Server* receives a message.

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121 SRev  ≜
122     ∧ Comm(Cop)!SRev
123     ∧ LET cop  ≜  Head(sincoming)
124       IN  ServerPerform(cop)
125     ∧ SRevCtx
126     ∧ UNCHANGED ⟨chins, c2ss⟩
127 ├──────────────────────────────────────────────────────────────────────┤
128 Next  ≜
129     ∨ ∃ c ∈ Client : Do(c) ∨ Rev(c)
130     ∨ SRev

132 Fairness  ≜
133     WF_vars(SRev ∨ ∃ c ∈ Client : Rev(c))

135 Spec  ≜  Init ∧ □[Next]_vars   ∧ Fairness
136 ├──────────────────────────────────────────────────────────────────────┤
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In *Jupiter* (not limited to *XJupiter*), each client synchronizes with the server. In *XJupiter*, this is expressed as the following *CSSync* property.

```
141 CSSync  ≜
142     ∀ c ∈ Client : (ds[c] = ds[Server]) ⇒ c2ss[c] = s2ss[c]
143 └──────────────────────────────────────────────────────────────────────┘
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