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FIFO Run-to-completion Event-based Programming Considered Harmful

Structured Network Programming

Ulf Wiger
Senior Software Architect
Ericsson AB, IMS Gateways
<ulf.wiger@ericsson.com>

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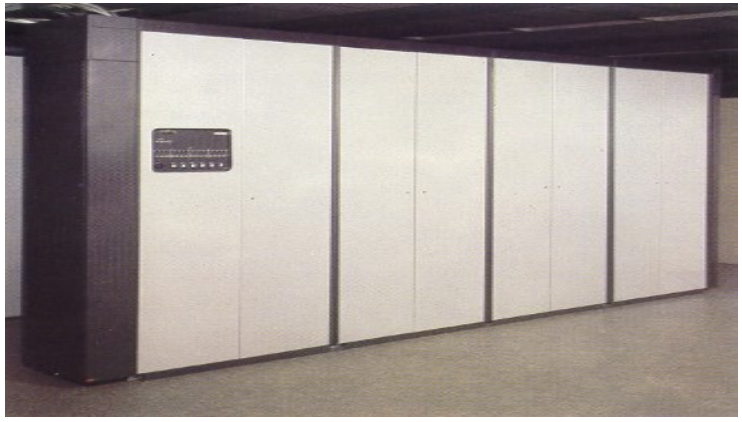
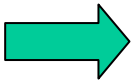
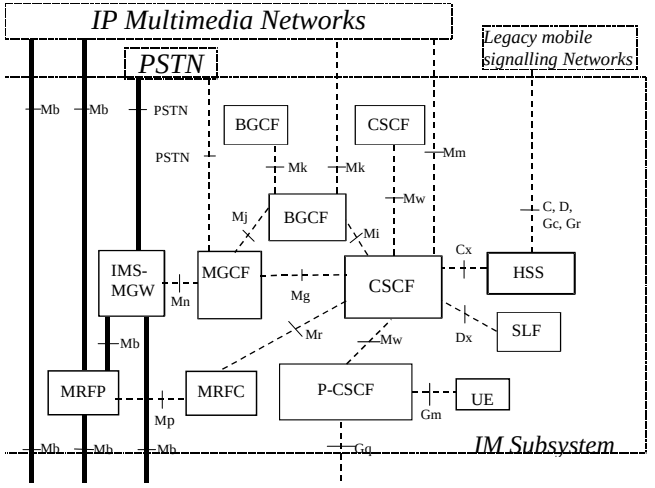
Trend: monoliths ⇒ networks of loosely coupled components.

- ⇒ stateful multi-way communication, delay issues and partial system failures
- No common insight yet into how this affects SW complexity (suspect that most people think it simplifies things...)







http://www.3gpp.org/ftp/Specs/archive/23_series/23.002/

Claims

1. Ability to filter messages with implicit buffering (”selective receive”) is vital for proper state encapsulation.
   - Otherwise, complexity explosion is inevitable (in certain situations.)
2. Inline selective receive keeps the logical flow intact – no need to maintain your own ”call stack”.

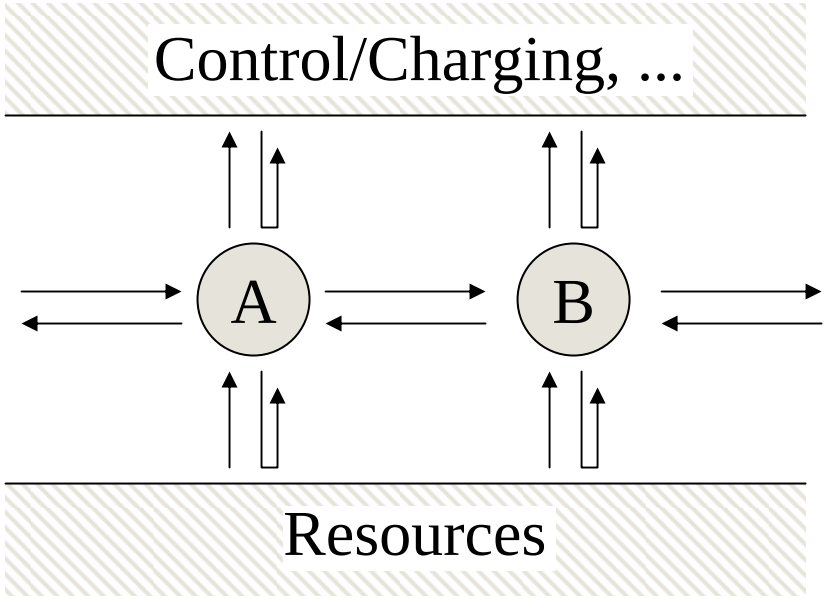
(1) is more important than (2).

The ability to implement complex state machines well will most likely become a key competitive edge.

Example Scenario

- Each ”session” is represented by one or more stateful processes (as in CSP)
- Each control process interacts with multiple uncoordinated message sources
- Message sequences may (and invariably will) interleave

Traditional ”Half-Call” model



A = originating side
B = terminating side

FIFO, Run-To-Completion (RTC) semantics:

- Thread of control owned by central event loop
- For each message, an associated method is called
- The method executes, then returns control to the main loop
- Typically, the event loop dispatches messages for multiple ”process” instances
  => an instance may never block.
- Examples: UML, common C++ pattern, OHaskell

Selective Receive semantics

- Each process instance specifies a subset of messages that may trigger method dispatch at any given time
- If the process owns the thread of control, this is done in a blocking ”system call” (e.g. the ’receive ... end’ language construct in Erlang, or the select() function in UNIX.

Selective receive is not a new concept

- The select() system call first appeared in 4.2BSD 1982
  - Allowed for blocking wait on a set of file descriptors.
  - (Needs to be coupled with e.g. getmsg() in order to fetch the message.)
  - Now supported by all unices.
- MPI* has API support for blocking selective receive.
- Erlang was first presented in 1987.

* http://www-unix.mcs.anl.gov/mpi/

Asynchronous Programming still dominates – why?

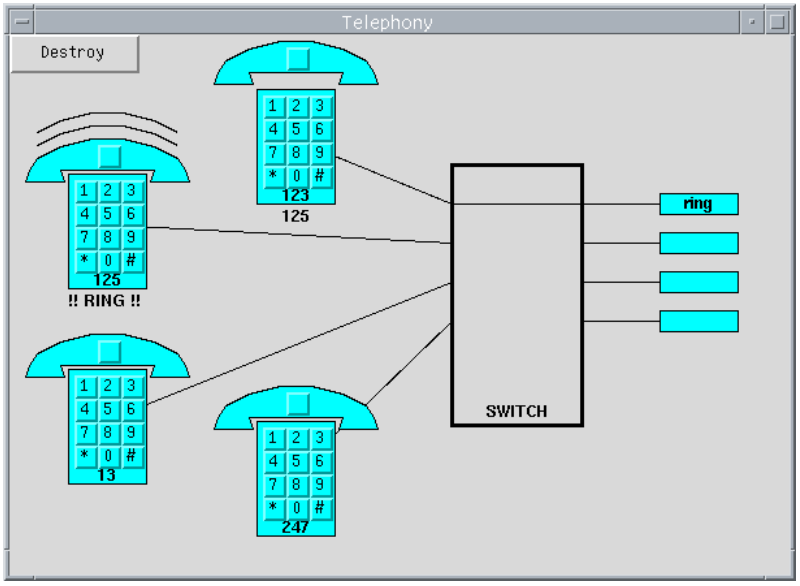
- Synchronous programming is considered slow.
- Reasoning about event-based programming seems easier.
- Easy to build a fast, simple event-based prototype.
- It's not clear what you give up by not programming synchronously!
- *(and blocking RPC is not the whole secret – selective receive is the powerful enabler.)*

Programming Experiment

- Demo system used in Ericsson's Introductory Erlang Course (assignment: write a control program for a POTS subscriber loop)
- We will re-write the control loop using different semantics.

- Note well: we don't handle errors in our example (usually the most complex part.)

"POTS": Plain Ordinary Telephony System – Trivial schoolbook example of telephony (as simple as it gets)



Demo...

POTS Control Loop – Original Impl. (1/3)

```
start() -> idle().

idle() ->
  receive
     {?lim, offhook} ->
         lim:start_tone(dial),
         getting fir
     {?lim, {di
         idle()
     {?hc, {req
         Pid !
         lim:st
         ringin
     Other ->
         io:for
         idle()
    end.
```

inline selective receive

Synchronous HW control

```
start_tone(Tone)->
  call({start_tone, Tone}).

call(Request) ->
  Ref = make_ref(),
  lim ! {request, Request, Ref, self()},
  receive
    {?lim, Ref, {_ReplyTag, Reply}} ->
        Reply
  end.
```

POTS Control Loop – Original Impl. (2/3)

```
getting_first_digit() ->
   receive
     {?lim, onhook} ->
         lim:stop_tone(),
         idle();
     {?lim, {digit, Digit}} ->
         lim:stop_tone(),
         getting_number(Digit,
             number:analyse(Digit, number:valid_sequences()));
     {?hc, {request_connection, Pid}} ->
         Pid ! {?hc, {reject, self()}},
         getting_first_digit();
     Other ->
         io:format(”Unknown message ...: ~p~n", [Other]),
         getting_first_digit()
   end.
```

POTS Control Loop – Original Impl. (3/3)

```
calling_B(PidB) ->
    receive
     {?lim, onhook} ->
         idle();
     {?lim, {digit, _Digit}} ->
         calling_B(PidB);
     {?hc, {accept, PidB}} ->
         lim:start_tone(ring),
         ringing_A_side(PidB);
     {?hc, {reject, PidB}} ->
         lim:start_tone(busy),
         wait_on_hook(true);
     {?hc, {request_connection, Pid}} ->
         Pid ! {?hc, {reject, self()}},
         calling_B(PidB);
     Other ->
         io:format("Got unknown message...: ~p~n",[...]),
         calling_B(PidB)
    end.
...
```

Experiment:
Rewrite the program using an event-based model

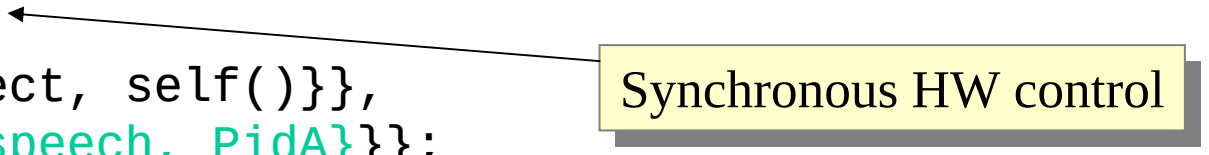
Event-based vsn, blocking HW control (1/3)

```
%% simple main event loop with FIFO semantics
event_loop(M, S) ->
   receive
      {From, Event} ->
          dispatch(From, Event, M, S);
      {From, Ref, Event} ->
          dispatch(From, Event, M, S);
      Other ->
          io:format(”Unknown msg: ~p~n", [Other]),
          exit({unknown_msg, Other})
    end.

dispatch(From, Event, M, S) when atom(Event) ->
   {ok, NewState} = M:Event(From, S),
   event_loop(M, NewState);
dispatch(From, {Event, Arg}, M, S) ->
   {ok, NewState} = M:Event(From, Arg, S),
   event_loop(M, NewState).
```

Event-based vsn, blocking HW control (2/3)

```
offhook(?lim, #s{state = idle} = S) ->
   lim:start_tone(dial),
   {ok, S#s{state = getting_first_digit}};
offhook(?lim, #s{state = {ringing_B_side, PidA}} = S) ->
   lim:stop_ringing(),
   PidA ! {?hc, {connect, self()}},
   {ok, S#s{state = {speech, PidA}}};
offhook(From, S) ->
   io:format("Unknown message in ~p: ~p~n",
             [S#s.state, {From, offhook}]),
   {ok, S}.
```



Event-based vsn, blocking HW control (3/3)

```
onhook(?lim, #s{state = getting_first_digit} = S) ->
   lim:stop_tone(),
   {ok, S#s{state = idle}};
onhook(?lim,#s{state={getting_number,{_Num,_Valid}}} = S) ->
   {ok, S#s{state = idle}};
onhook(?lim, #s{state = {calling_B, _PidB}} = S) ->
   {ok, S#s{state = idle}};
onhook(?lim, #s{state = {ringing_A_side, PidB}} = S) ->
   PidB ! {?hc, {cancel, self()}},
   lim:stop_tone(),
   {ok, S#s{state = idle}};
onhook(?lim, #s{state = {speech, OtherPid}} = S) ->
   lim:disconnect_from(OtherPid),
   OtherPid ! {?hc, {cancel, self()}},
   {ok, S#s{state = idle}};
...
```

A bit awkward
(FSM programming ”inside-out”),
but manageable.

Add the non-blocking restriction

(first, naive, implementation)

Now, assume we are not allowed to block (common restriction, 1/3)


```
offhook(?lim, #s{state = idle} = S) ->
   lim_asynch:start_tone(dial),
   {ok, S#s{state = {{await_tone_start,dial},
                     getting_first_digit}}};
offhook(?lim, #s{state = {ringing_B_side, PidA}} = S) ->
   lim_asynch:stop_ringing(),
   PidA ! {?hc, {connect, self()}},
   {ok, S#s{state = {await_ringing_stop, {speech, PidA}}}};
offhook(?lim, S) ->
   io:format("Got unknown message in ~p: ~p~n",
       [S#s.state, {lim, offhook}]),
   {ok, S}.
```

... not allowed to block (2/3)

```
digit(?lim, Digit, #s{state = getting_first_digit} = S) ->
    %% CHALLENGE: Since stop_tone() is no longer a synchronous
    %% operation, continuing with number analysis is no longer
    %% straightforward. We can either continue and somehow log that
    %% we are waiting for a message, or we enter the state await_tone_stop
    %% and note that we have more processing to do. The former approach
    %% would get us into trouble if an invalid digit is pressed, since
    %% we then need to start a fault tone. The latter approach seems more
    %% clear and consistent. NOTE: we must remember to also write
    %% corresponding code in stop_tone_reply().
    lim_asynch:stop_tone(),
    {ok, S#s{state = {await_tone_stop,
                      {continue, fun(S1) ->
                                     f_first_digit(Digit, S1)
                                 end}}}};
```

...not allowed to block (3/3)

```
start_tone_reply(?lim, {Type, yes},
   #s{state = {{await_tone_start, Type}, NextState}} = S) ->
   {ok, S#s{state = NextState}}.

stop_tone_reply(?lim,_,#s{state={await_tone_stop,Next}} =S) ->
   %%  CHALLENGE: Must remember to check NextState. An alternative would
   %%  be to always perform this check on return, but this would increase
   %%  the overhead and increase the risk of entering infinite loops.
   case NextState of
      {continue, Cont} when function(Cont) ->
          Cont(S#s{state = Next});
      _ ->
          {ok, S#s{state = Next}}
   end.
```

Quite tricky, but the program still isn't timing-safe. (Demo...)

Global State-Event Matrix

FIFO semantics, asynchronous hardware API

	idle	getting first digit	getting number	calling B	ringing A-side	speech	ringing B-side	wait on-hook	await tone start	await tone stop	await ringing start	await ringing stop	await pid with telnr	await conn-ect	await dis-connect
offhook	O	X	X	X	X	X	O	X	X	X	D	X	X	X	X
onhook	X	O	O	O	O	O	O	O	D	D	D	D	D	D	D
digit	—	O	O	—	—	—	—	—	D	D	D	D	D	D	—
connect	—	—	—	—	O	—	—	—	D	X	X	X	X	X	X
request connection	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
reject	—	—	—	O	—	—	—	—	X	X	X	X	X	X	X
accept	—	—	—	O	—	—	—	—	X	X	X	X	X	X	X
cancel	—	—	—	—	—	—	—	—	X	D	D	D	X	D	X
start tone reply	X	X	X	X	X	X	X	X	O	X	X	X	X	X	X
stop tone reply	X	X	X	X	X	X	X	X	X	O	X	X	X	X	X
start ringing reply	X	X	X	X	X	X	X	X	X	X	O	X	X	X	X
stop ringing reply	X	X	X	X	X	X	X	X	X	X	X	O	X	X	X
pid with telnr reply	X	X	X	X	X	X	X	X	X	X	X	X	O	X	X
connect reply	X	X	X	X	X	X	X	X	X	X	X	X	X	O	X
disconnect reply	X	X	X	X	X	X	X	X	X	X	X	X	X	X	O

Apparent Problems

- The whole matrix needs to be revisited if messages/features are added or removed.
- What to do in each cell is by no means obvious – depends on history.
- What to do when an unexpected message arrives in a transition state is practically never specified (we must invent some reasonable response.)
- Code reuse becomes practically impossible.

Non-blocking version, using message filter (1/2)

```
digit(?lim, Digit, #s{state = getting_first_digit} = S) ->
   %% CHALLENGE: ...<same as before>
   Ref = lim_asynch:stop_tone(),
   {ok, S#s{state = {await_tone_stop,
                     {continue, fun(S1) ->
                                    f_first_digit(Digit, S1)
                                end}}},
    #recv{lim = Ref, _ = false}};
```

Accept only msgs tagged with Ref, coming from 'lim';
buffer everything else.

The continuations are still necessary, but our sub-states are now insensitive to timing variations.

Non-blocking version, using message filter (2/2, the main event loop)

```
event_loop(M, S, Recv) ->
   receive
      {From, Event} when element(From, Recv) == [] ->
          dispatch(From, Event, M, S);
      {From, Ref, Event} when element(From, Recv) == Ref ->
          dispatch(From, Event, M, S);
      {From, Ref, Event} when element(From, Recv) == [] ->
          dispatch(From, Event, M, S)
   end.

dispatch(From, Event, M, S) when atom(Event) ->
    handle(M:Event(From, S), M);
dispatch(From, {Event, Arg}, M, S) ->
    handle(M:Event(From, Arg, S), M).

handle({ok, NewState}, M) ->
    event_loop(M, NewState);
handle({ok, NewState, Recv}, M) ->
    event_loop(M, NewState, Recv).
```

Properties of filtered event loop

- Can be implemented in basically any language (e.g. extending existing C++ framework.)
- Solves the complexity explosion problem.
- Doesn’t eliminate the need for continuations (this affects readability – not complexity)

Real-Life Example

Code extract from the AXD301-based ”Mediation Logic” (ML)

```
%% We are waiting to send a StopTone while processing a StartTone and now
%% we get a ReleasePath. Reset tone type to off and override StopTone
%% with ReleasePath since this will both clear the tone and remove connection.
cm_msg([?CM_RELEASE_PATH,TransId,[SessionId|Data]] = NewMsg,
       HcId, #mlgCmConnTable{
                  sessionId = SessionId,
                  sendMsg = ?CM_START_TONE_RES,
                  newMsg = {cm_msg,
                            [?CM_STOP_TONE|Msg]}} = HcRec,
       TraceLog) ->
   NewHcRec = HcRec#mlgCmConnTable{
                       newMsg = {cm_msg, NewMsg},
                                 toneType = off},
   NewLog = ?NewLog({cm_rp, 10}, {pend, pend}, undefined),
   mlgCmHccLib:end_session(
       pending, NewHcRec, [NewLog | TraceLog], override);
```

Real-Life Example

Code extract from the AXD301-based ”Mediation Logic” (ML)

```
%%  If we are pending a Notify Released event for a Switch Device, override
%%  with ReleasePath.
cm_msg([?CM_RELEASE_PATH,TransId,[SessionId|Data]] = NewMsg,
       HcId,
       #mlgCmConnTable{
           sessionId = SessionId,
           newMsg = {gcp_msg, [notify, GcpData]},
           deviceType = switchDevice,
           path2Info = undefined} = HcRec,
       TraceLog) ->
   NewHcRec = HcRec#mlgCmConnTable{newMsg= {cm_msg, NewMsg}},
   NewLog = ?NewLog({cm_rp, 20}, {pend, pend}, undefined),
   mlgCmHccLib:end_session(
        pending, NewHcRec, [NewLog | TraceLog], override);
```

Real-Life Example

Code extract from the AXD301-based ”Mediation Logic” (ML)

```
%% Getting a ReleasePath when pending a Notify Released event is a bit
%% complicated. We need to check for which path the ReleasePath is for and
%% for which path the notify is for. If they are for different paths we are
%% in a dilemma since we only can be in pending for one of them. As a simple
%% way out we just treat this as an abnormal release for now.
cm_msg([?CM_RELEASE_PATH,TransId,[SessionId|Data]] = NewMsg,
       HcId,
       #mlgCmConnTable{
           sessionId = SessionId,
           newMsg = {gcp_msg, [notify, GcpData]},
           deviceType = switchDevice} = HcRec,
       TraceLog) ->
   mlgCmHcc:send_cm_msg(?CM_RELEASE_PATH_RES,
                        ?MSG_SUCCESSFUL, TransId, SessionId),
   NewHcRec = HcRec#mlgCmConnTable{newMsg = abnormal_rel},
   NewLog = ?NewLog({cm_rp, 30}, {pend, pend}, undefined),
   mlgCmHccLib:end_session(pending, NewHcRec,
                           [NewLog | TraceLog], override);
```

Observations

- Practically impossible to understand the code without the comments
- Lots of checking for each message to determine exact context
  (basically, a user-level call stack.)
- A nightmare to test and reason about
- (The production code has now been re-written and greatly simplified.)

ML State-Event Matrix (1/4)

State / Triggers	Null	Setup	Add	Connected	Release	ModifyConn	Modify	ToneActive	CotActive	Override	Pending	Seized	Move	Prepare	Broken
EstablishPath	1,2	y	y	40, 41, 42, 43, 44	84	y	y	123, 124	129, 130	y	y	213	220, y	y	235, 236, 237, 259
ModifyPath	y	y	y	45, 46	y	y	y	y	y	y	y	y	y	y	y
ReleasePath	4	13	y	47, 48, 49, 50, 51, 52	85, 86	13	13	y	131	134, 135, 136	150, 151, 152	y	13	13	238
StartTone	5	y	y	53	87	y	y	125	y	y	y	y	y	y	239
StopTone	5	y	y	54	88	y	111, 112, 113	126	y	137	y	y	y	y	240
PreparePath	254	y	y	55	y	y	y	y	y	y	y	y	y	y	y
BreakPath	y	y	y	56	y	y	y	y	y	y	y	y	y	y	y
SeizeDevice	6	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
ReleaseDevice	7	13	13	57, 58	89	13	13	NA	NA	138	153, 154, 155, 156	214	13	NA	241

Action procedures:

N/A	Not applicable
x	No action, ignore the error
y	Return protocol error, remain in same state
A	Anomaly, log

Alternative execution paths depending on context

ML State-Event Matrix (2/4)

State / Triggers	Null	Setup	Add	Connected	Release	ModifyConn	Modify	ToneActive	CotActive	Override	Pending	Seized	Move	Prepare	Broken
AddReply	A	A	29, 30, 31, 32, 33, 256	A	A	A	A	A	A	A	157, 158, 159, 160, 161, 162, 163, 164, 165, 166, 167	A	221	A	A
SubtractReply	A	A	A	A	90, 91	A	A	A	A	139	168, 169, 170, 171	A	A	A	A
ModifyReply	A	A	A	A	A	105, 106	114, 115, 116, 117, 118, 119	A	A	A	172, 173, 174, 175, 176, 177, 178, 179	A	A	A	A
MoveReply	A	A	A	A	A	A	A	A	A	140, 141	180	A	222, 223, 224, 225, 226	A	A
Notify - establish	x	14	34, 35, 36	59, 60	92, 93	A	A	A	A	A	181	215	227, 228	A	260
Notify - release	x	15	15	61, 62, 63, 64, 65, 66	94, 95	15	15	A	A	142	182, 183, 184, 185, 186	216	15	15	242, 243

ML State-Event Matrix (3/4)

State / Triggers	Null	Setup	Add	Connected	Release	ModifyConn	Modify	ToneActive	CotActive	Override	Pending	Seized	Move	Prepare	Broken
hc_msg - setup	8	A	A	67, 68, 69, 70, 71	96	A	A	127	132	A	187	217, 218	229, 230	A	244, 245, 246, 247, 248, 249, 250, 261, 262
hc_msg - setup_res	A	16, 17, 18, 19, 20, 21, 22, 255	A	A	A	A	A	A	A	A	188, 189, 190, 191, 192, 193, 194, 195	A	A	A	A
hc_msg - modify	A	A	A	72	A	A	A	A	A	A	196	A	A	A	A
hc_msg - modify_res	A	A	A	A	A	107, 108	120	A	A	A	A	A	A	A	A
hc_msg - release	9, 10	23	23	73, 74, 75, 76, 77	97, 98	23	23	A	A	143	197, 198, 199, 200, 201, 202, 203	A	23	23	251
hc_msg - release_res	x	A	A	A	99, 100	NA	NA	NA	NA	144	A	A	A	A	A
hc_msg - prepare	11	A	A	257	101	A	A	A	A	A	204, 205, 206, 207, 208	A	A	A	A
hc_msg - prepare_res	A	A	A	A	A	A	A	A	A	A	A	A	A	232, 233, 258	A
hc_msg - break	A	A	A	78	A	A	A	A	A	A	A	A	A	A	A
hc_msg - break_res	A	A	A	79	A	A	A	A	A	A	A	A	A	A	A

ML State-Event Matrix (4/4)

State / Triggers	Null	Setup	Add	Connected	Release	ModifyConn	Modify	ToneActive	CotActive	Override	Pending	Seized	Move	Prepare	Broken
hc_timeout	NA	24, 25, 26, 27	NA	NA	102	109	121	NA	NA	145	209	NA	NA	234	NA
gcp_timeout	A	A	37, 38, 39	A	103	110	122	A	A	146, 147	210	A	231	A	A
abnormal_rel	x	28	28	80, 81, 82, 83	104	28	28	128	133	148, 149	211, 212	219	28	28	252, 253

Observations... 

Observations re. ML

- Still, only the external protocol is handled this way (the state machine uses synchronous calls towards internal APIs) – otherwise, it would *really* be bad.
- This is the semantics offered by UML(*) as well (UML gives lots of abstraction support, but only for the sequential parts – not for state machines.)
- This seems analogous to
  - Dijkstra's "Goto considered harmful", and
  - local vs. global variables.

(*) Only partly true – see 'deferrable event', UML 1.5, part 2, pp 147

Questions?