mo'ule with 20 inputs, ea)h havin% + values to be stimulate'. So you woul' have to 'e#ine + to the power o# 20 ,-.+,/01,4/1,040,02+2 tests. Consi'erin% that in real li#e mo'ules use)ounters an' threshol's, the numbers %et even worse. Thus the)osts #or maintainin% an' 'e#inin% mo'ule tests espe)ially #or)omple* mo'ules limit its use.

3e%ar'in% the 4-&o'el by Barry Boehm the mo'ule test is #ollowe' by the inte%ration test. 5urin% the 'evelopment o# the new .6-Troni) by 5aimler a Si7 was built 1ÓÀÓArA-P

the inte%ration test was 'one be#ore the mo'ule test.

8rom that)onte*t the i'ea was born to 'erive the mo'ule test #rom the inte%ration test. The mo)! ob e)ts nee'e' to run the mo'ule test)oul' be %enerate' automati)-ally #rom the inte%ration test o# the Si7. This metho' was use' to test mo'ules with hi%h)omple*ity ,40-100 inputs, in)lu'in% analo% sensor values2 an' it turne' out that the e##ort to 'e#ine an' maintain su)h tests was very low. The mo'ule test in system)onte*t was well a))epte'.

1g ej i#&uSilduxl!x l#trlTa!ny%lduxl)ydrt1lit#dbarxlrx1nap1xlbaildtlTa!xlnc

hi%hly e##i)ient.

1.1 The Development Process

At 5aimler there are two 'evelopment)y)les ,a!a 4A-)y)les2 a year. 9hile the 4-part is #ollowin% the 4-&o'el by Barry Boehm, the A-part is about tunin% the parameters su)h that the)ar per#orms best. $n the #ollowin% we restri)t to the 4-)y)le.

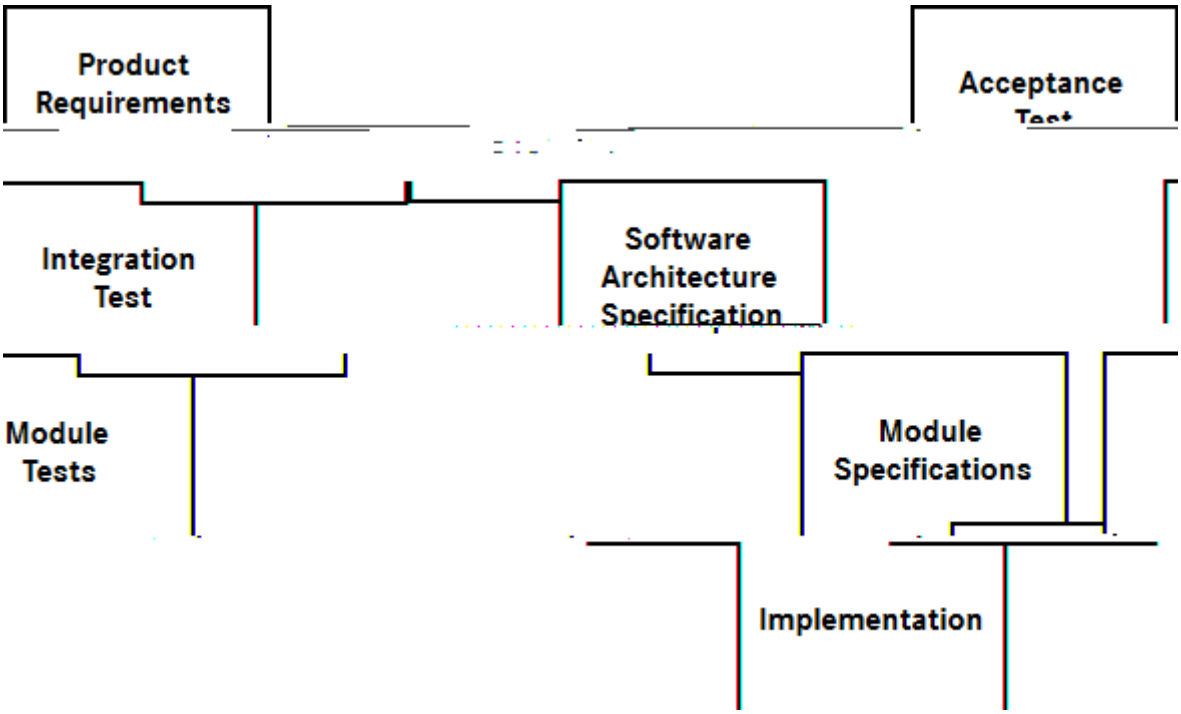

Diagram 1: The !Model

8rom the #un)tion 'eveloper:s point o# view this pro)ess is;

- Spe)i#y your #un)tion,
- wait until it is implemente' by the so#tware en%ineers,
- #lash the test so#tware to the <i7 or)ar, test it an'
- report the test result.

This pro)ess turne' out to be a bottlene)!.

- =a)h loop ta!es its time be)ause at least two en%ineers are involve' until you)an test.
- The spe)i#i)ation o# the 'esi%n en%ineer is o#ten misinterprete' by the so#t-ware en%ineer. Thus a''in% more loops.
- =as â mor.E#YAÑn%n%n%ióe%is o#trn%n% poin$!paa%B/n%)ay#ïn%t@Ba@t#%@Bt@rranÀr n

)hain #rom the)ar an' use it with the Si7. An' be)ause in the virtual worl' there is no ban'wi'th limitation o# the CA@, you)an measure tens o# thousan's o# measurements at on)e.

$# a 'esi%n en%ineer wants to test his i'ea, he)han%es the mo'el, pushes a button an' within minutes he %ets the Si7 with his mo'i#i)ations, rea'y #or an inte%ration test. A#ter testin% intensively he)an 'e)i'e #or the best option an' #ormulate the one spe)i#i)ation #or the so#tware en%ineer.

Be)ause the Si7 pre-testin% is easily 'one so#tware 'e#e)ts)an be #oun' as early as possible. @ote that both the 'esi%n en%ineer an' the so#tware en%ineer bene#it #rom the Si7.

". The Module Test

9 hile the inte%ration test evaluates the system behavior, espe)ially how the mo'ules o# the system intera)t with ea)h other, the mo'ule test #o)usses on a mo'ules internal lo%i). 8or the sa!e o# so#tware (uality both levels o# 'etail must be)overe'.

$n theory mo'ules shoul' be small an' have less than 10 inputs an' outputs. The more)omple* mo'ules are well stru)ture' an' hi%hly mo'ular #rom the insi'e. An' the mo'ules are easy to un'erstan', well 'o)umente' an' some parts)an even be reuse'.

%. Module Test in System Context

The)hallen%e is to set up mo'ule testin% #or)omple* mo'ules su)h that

- the)osts implementin% a test is in'epen'ent o# the)omple*ity o# the mo'ule,
- the test is ba)!war')ompatible to)lassi) mo'ule testin% an'
- the test is robust in terms o# inter#a)e)han%es o# the mo'ule.

This is the)o-simulation that is use' #or the inte%ration test.

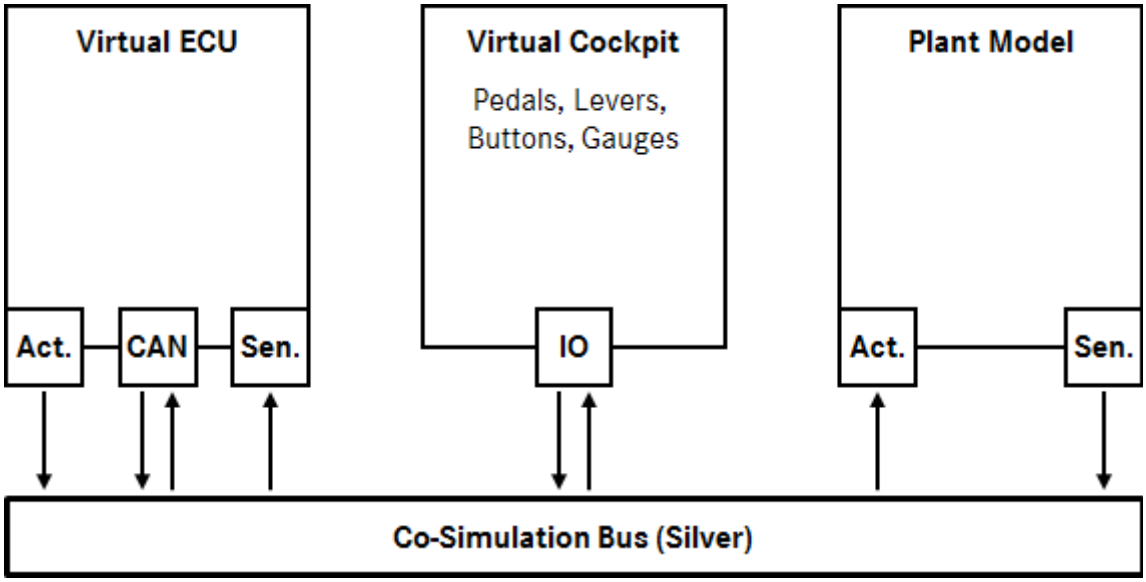

Diagram ": The co!simulation

The =C>)omes #rom the buil' pro)ess that automati)ally inte%rates all mo'ules an' emulates the ?CP- an' CA@-)ommuni)ation. The plant mo'el is)reate' by 5ymola simulatin% the har'ware o# the transmission. The virtual)o)!pit o##ers buttons an' sli'ers to intera)t with the virtual)ar. All is inte%rate' usin% the)o-simulation bus.

9hat has)han%e' is the representation o# the)ontrol so#tware o# the =C>. $# we isolate one mo'ule then the rest o# the)ontrol so#tware be)omes an a'apter between the mo'ule ? an' the)o-simulation bus. Sin)e we alrea'y have solve' the problem how to inte%rate all mo'ules, the a'apter)omes #or #ree.

A#ter automati)ally 'eterminin% the inputs o# mo'ule ? we a'' an appropriate bypass)ontrol panel to the)o)!pit o# the Si7. Thus the Si7 be)omes the mo'ule test in system)onte*t.

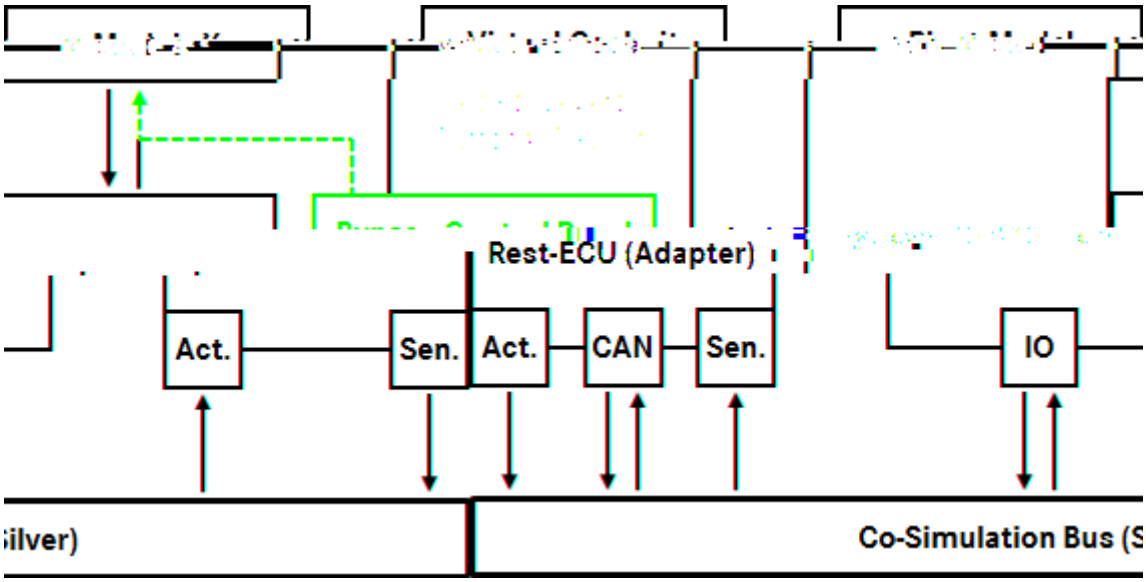

Diagram ': The Module Test in System Context

$# you re)or' the outputs o# the virtual)o)!pit an' the bypass)ontrol panel you)an replay any stimulus. Thus you)an re)or' the stimulus by simply 'rivin% the virtual)ar an' usin% the bypass)ontrol panel at the ri%ht point o# time.

The re(uirements mentione' above hol' true;

- The)osts to implement the mo'ule test are in'epen'ent o# the)omple*ity o# the mo'ule be)ause most o# the time you use the virtual)o)!pit as input an' the bypass)ontrol panel that is automati)ally %enerate'.
- The mo'ule test in system)onte*t is)ompatible with the)lassi) mo'ule test. 8rom the very be%innin% o# the simulation use the bypasses only to stimulate the mo'ule. $n this)ase, all other mo'ules still are e*e)ute', but they are out o# the test loop.
- $# the inter#a)e o# mo'ule ?)han%es most o# the stimulus re)or'e' will still wor! sin)e the a'apter automati)ally)han%es too. Bne)an)onstru)t)ounter e*ample #or this, but in pra)ti)e they turne' out to be rare.

The remainin% part is to evaluate the mo'ule behavior. To 'o so we use so-)alle' wat)hers. They have the #ollowin% properties;

- 9at)hers are assi%ne' to one or more stimulus.
- 9at)hers have a Boolean e*pression to 'etermine when the evaluation starts. $n the)ase o#)lassi) mo'ule testin% this woul' be)he)!in% the time.

- 9at)hers have a Boolean e*pression to 'etermine i# the test su))ee'e'. 8or this)he)! you)an 'e#ine a toleran)e time in whi)h the test has to su))ee' or you)an 'e#ine that the su))ess state has to stay true #or some time.
- Cou)an)on)atenate wat)hers to a list o# wat)hers.

$n pra)ti)e 'e#inin% wat)hers ta!es #rom less than a minute ,simple)he)!2 up to #ive minutes ,)on)atenate' wat)hers with)omple* Boolean e*pressions2. A%ain the re-(uirements mentione' above are still vali'.

5urin% the test the)o'e)overa%e is measure' usin% the CTC-tool by Testwell. A#ter your tests #inishe' you %et a report visualiDin% whi)h lines o# the)-)o'e have been e*e)ute' an' whi)h still miss. 8rom this analysis you %ain !nowle'%e how to in-)rease the)o'e)overa%e an' how the ne*t stimulus has to be 'e#ine'.

'. Conclusion and (esults

This metho' has been applie' to the .6-Troni) 'evelopment #or a set o# very)om-ple* mo'ules havin% up to 100 inputs. This wor! was 'ele%ate' to a test en%ineer who)reate' test stimulus usin% the 'o)umentation o# the)ontrol so#tware. A#ter one wee! o# testin% a)o'e)overa%e o# about 10A)oul' be a)hieve' an' the tests were presente' to the 'esi%n en%ineer in)har%e. A#ter 'is)ussin% some 'etails an' one more wee! o# testin% the)o'e)overa%e raise' to about .0A. The mo'ule test in system)onte*t was well a))epte' be)ause the han'lin% was easy an' #ast.

8or very simple mo'ules the)lassi) mo'ule test was better to use sin)e all you have to 'o is #ill up a sprea'-sheet with inputs an' outputs. But with raisin%)omple*ity the mo'ule test in system)onte*t was mu)h more e##i)ient in terms o# test 'epth an' time)osts.

This last point still)oul' be solve' be)ause the mo'ule test in system)onte*t is ba)!war')ompatible to the)lassi) mo'ule test. >sin% the sprea'-sheet with inputs an' outputs one)oul' %enerate everythin% nee'e' to run the same test as a mo'ule test in system)onte*t.

The Authors

" "Q` &eSA6T ar! "ie#er
5aimler A6
e A6 Strate%y an' CooT oTaEavEamlaeay1@TStaTA6