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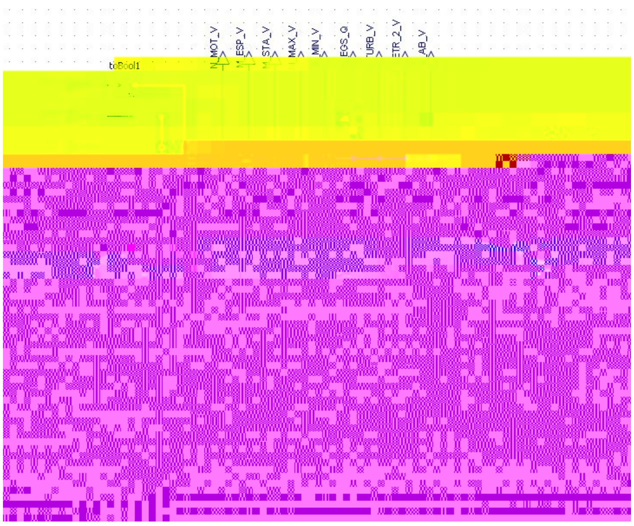
. e 5resent and dis&uss the * odeli&a)'ased de6elo5)ment en6ironment &urrentl7 used '7 Daimler to de)6elo5 5o8ertrain &ontrol soft8are for 5assenger &ars0 , esides 8ell &ali'rated 6ehi&le models, the en6iron)ment su55orts automoti6e standards su&h as A29, * D:, CA;, and <C= to integrate &ontrol soft8are and simulated 6ehi&les on . indo8s =Cs0

* ore and more automoti6e fun&tions are im5lemen)ted using soft8are0 (en&e, there is an in&reasing de)mand to su55ort the &orres5onding de6elo5ment 5ro)&ess using 6irtual, i0e0 simulation)'ased de6elo5)ment en6ironments0



>irtuall7 &ou5ling &ontrol strategies 8ith 5lant mod)els is standard te&hnolog7 toda7, mostl7 using &om)mon)5la&e tools su&h as * atla'?#imulink for 5re)de6elo5ment of &ontrol algorithms0 %his 5a5er 5resents te&hnolog7 targeted to8ard the late stages in the de6elo5ment 5ro&ess, like tuning, 6alidating and de'ugging the entire &ontroller soft8are in &losed loo5 8ith simulated 5lant models0 >irtuali@ing these later engineering tasks re4uires 5lant models 8ith in)&reasingl7 higher 4ualit7 A5h7si&al effe&ts modeled and 4ualit7 of &ali'rationB and near)5rodu&tion &on)troller soft8are A5er&entage of the &ontroller soft)8are in&luded, 5arameteri@ation using 5rodu&tion 5arameter sets and ada5tation of the soft8are to the 5lantB to 'e &ou5led0

A tool)&hain su55orting su&h &ou5ling should

- 'e eas7 to set u5 and use '7 automoti6e de)6elo5ers 8ho are usuall7 not &om5uter s&i)entists
- su55ort man7 of the engineering tasks usu)all7 5erformed 8ith 5h7si&al 5rotot75es to allo8 for front)loading
- su55ort short turn)around times, i0e0 minim)i@e the time 'et8een editing of &ontrol soft)8are and 6alidation of the resulting 'eha6ior on s7stem le6el to hel5 find 5ro'lems earl7
- 5ro6ide 'uilt)in su55ort for standards and de)fa&to standards used in automoti6e soft)8are de6elo5ment to allo8 &ost)effe&ti6e use of eCisting information sour&es
- su55ort distri'uted de6elo5ment and eC

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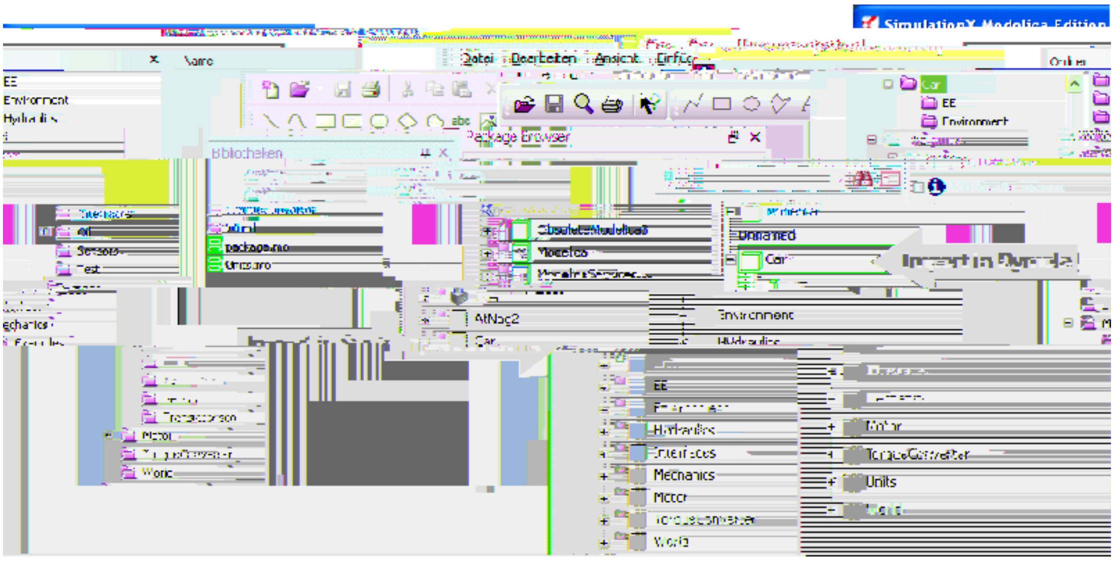
&ols or tool 5oli&7 &onsiderations0



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tion< 30!0 *odels and li'raries are stored on hard disk as 0mo files0 ,oth tools are a'le to read these files 8ith no s5e&ifi& modifi&ation, i0 e0 the7 use eC)a&tl7 the same files for dis5la7ing eCa&tl7 the same stru&ture0 :igure ! sho8s a s&reenshot of the dire&t)or7 stru&ture and the integration in e6er7 tool0
%his 5ro6es that one design goal of *odeli&a and the *odeli&a #tandard 9i'rar7 A*#9B has 'een rea&hed no8, namel7 to 5ro6ide a tool)6endor inde5endent re5resentation format for simulation models0 %here are ho8e6er still a fe8 issues to 'e sol6ed to full7 rea&h 6endor inde5enden&e of the *#9F

- %he definition of ta'les in *odeli&a #tand)ard 9i'rar7 is 'ased on eCternal fun&tions0 %he im5lementation of these fun&tions is not 5art of the li'rar7 itself and has to 'e done '7 tool 6endors0 -n &onse4uen&e of missing s5e&ifi&ation the different im5lementations are not &om5letel7 &om5ati'le0
- . ith the eC&lusi6e usage of eCternal fun&)tions it is diffi&ult to ada5t the im5lementa)tion on the re4uirements of the underl7ing tool0 %he su'stitution of eCternal fun&tions '7 eCternal o'3e&ts 8ould im5ro6e the im)5lementation &a5a'ilities0
- :or users of a *odeli&a tool it is diffi&ult to de&ide 8hether a used &onstru&t is &om5at)i'le to *odeli&a language s5e&ifi&ation or not Ae0g0 &lassDire&tor7 fun&tionB0 All tool de5endent eCtensions of *odeli&a language should 'e marked as 6endor s5e&ifi& similar to eCisting 6endor s5e&ifi& annotations0
- *odeli&a li'raries often use different 6ersion of annotations for gra5hi&al o'3e&ts or attri')utes 8hi&h are in6alid in the 5arti&ular &on)teCt Ae0g0 fillColor for linesB0 . hile se6eral tools ignore su&h annotations other 5rograms generate error messages, 8hi&h &an 'e a little 'it &onfusing for users and de6elo5ers0 :or that reason a stronger 6alidation of an)notations 8ould 'e 5refera'le0

%o &reate a #oft8are in the 9oo5 setu5, the *odeli&a model is then eC5orted0 -n 5re6ious 7ears, the C &ode generated '7 either D7mola or #imulation< from a gi6en *odeli&a model has 'een 8ra55ed and &om)5iled for eCe&ution '7 one of the #i9 tools des&ri'ed in #e&tion 30 :or eC5ort, s5e&ial 8ra55er &ode had to 'e de6elo5ed for ea&h simulation tool, and e6en for ea&h 6ersion of su&h a tool, 8hi&h 8as time &onsum)ing and error 5rone0 Daimler started re&entl7 to use the :*- GIH de6elo5ed 8ithin the *odelisar 5ro3e&t as an eC5ort format for *odeli&a models0 %his stand)ard is su55orted '7 the latest 6ersions of #imula)tion<, D7mola, and #il6er0 %his remo6es the need to maintain 6ersion and 6endor s5e&ifi& 8ra55er &ode, 8hi&h further im5ro6es and s5eeds u5 the #i9)'ased de6elo5ment 5ro&ess0

Daimler uses #il6er G H and its in)house 5rede&essor ,a&k'one to 6irtuall7 integrate 6ehi&le models and &ontrol soft8are on . indo8s =Cs0 %ools su&h as #il)6er or ,a&k'one are mainl7 needed to su55ort 6ari ous standards and 4uasi)standards used for automot)i6e soft8are de6elo5ment0 De6elo5ers are familiar 8ith these standards and kno8 ho8 to use them0 Data is a6aila'le in these formats alread7 as 5art of the eCisting tool &hain and reuse is 6irtuall7 free of &ost0 :urthermore, using these data sour&es in the 6irtual de6elo5ment 5ro&ess allo8s earl7 6alidation of these data sour&es0 A 6irtual de6elo5ment en6ir)onment should therefore mimi&, emulate, or else ho8 su55ort these standards0 A fe8 eCam5les of ho8 the #i9 tool su55orts automoti6e standards is sho8n in :ig0 0

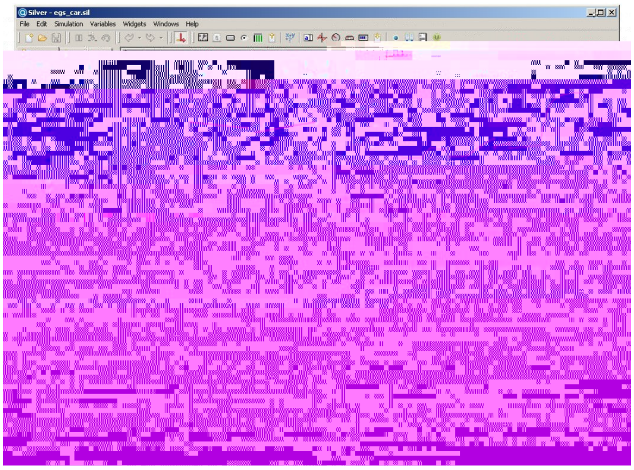
De6elo5ers t75i&all7 use tools su&h as CA;a5e A>e&torB or -;CA AE%A#B to measure signals and &ali'rate Afine)tuneB 5arameters of the &ontrol soft)8are in the running &ar or on a test rig using standard 5roto&ols su&h as CC= or <C=0 %he #i9 en6ironment im5lements this 5roto&ol0 #een from a measurement tool su&h as CA;a5e, a #i9 simulation 'eha6es 3ust like a real &ar0 De6elo5ers &an therefore atta&h his fa)6orite measurement tool to the #i9 to measure and &ali'rate using the same measurement masks, data sour&es and 5ro&edures the7 are using in a real &ar0

9ike8ise, automoti6e de6elo5ers use *D: files to store measurements0 %he #i9 &an load and sa6e this file format0 A measured *D: file &an e0 g0 'e used to dri6e a #i9 simulation0

Another eCam5le is A290 %his is a data'ase format used to store ke7 information a'out 6aria'les and Atuna'leB 5arameters of automoti6e &ontrol soft8are0 A29 &ontains e0 g0 the address of 6aria'les in the ECE, its 5h7si&al unit, &omment and s&aling inform)ation that tells ho8 to &on6ert the ra8 integer 6alue to a 5h7si&al 6alue0 %he #i9)en6ironment reads A29 files and uses the information to automate man7 tasks, su&h as s&aling of the integer 6aria'les of the &ontrol soft8are to mat&h the 5h7si&al 6aria'les of the 6ehi&le model0

(a6ing all these standards a6aila'le in the #i9 eases the task of a&tuall7 getting automoti6e &ontrol soft) 8are running on a =C, and doing useful things 8ith the resulting setu50 Control soft8are is t75i&all7 de) &om5osed into a num'er of so)&alled tasks Ai0 e0 fun&tions im5lemented in CB that are run '7 an R%D# Areal)time o5erating s7stemB su&h as D#EK0 *an7 tasks are 5eriodi&all7 eCe&uted 8ith a fiCed rate, e0 g0 e6er7 10 ms0 %o get su&h tasks running in #i9, the user has to 'uild an ada5ter as sho8n in :ig0 , i0 e0 a little C 5rogram that im5lements the #il6er module A=- and emulates the R%D# '7 &all) ing ea&h task on&e at e6er7 Aor e6er7 2nd, 3rd, 000B #i9 ma&ro ste50 %he #i9 tool is shi55ed 8ith the #,# A#il6er ,asis #oft8areB, i0 e0 C sour&es that make it eas7 to 'uild su&h an ada5ter '7 ada5ting tem5late ada5ter &ode0 A &hea5 alternati6e to 8riting an ada5ter is to use the #i9 toolJs su55ort for *A%) 9A,?#imulink and Realtime .orksho5 AR%.B0 Automoti6e soft8are is often de6elo5ed '7 first &re) ating a model of the &ontroller using #imulink0 %he soft8are 6ersions '7 &om5aring all signals &om5uted '7 these 6ersions0 %his is e0 g0 useful 8hen &he&king for e4ui6alen&e after refa&toring or &lean u5 of modules0

- F A #i9 simulation &an 'e dri6en '7 a s&ri5t, 8ritten e0 g0 in =7thon0 %his &an 'e used to im5lement o5timi@ation 5ro&edures, for 5erforming tests, or to trigger self)learn)ing algorithms that ada5t the &ontrol soft)8are to &ertain 5ro5erties of the AsimulatedB &ar, e0 g0 to &om5ensate aging of &om5on)ents0
- F -n &on3un&tion 8ith the test &ase generator %est . ea6er, the #i9 tool allo8s the s7stemati& testing of &ontrol soft)8are0 %est . ea6er generates thousands of test &ases 8hi&h are then eCe&uted '7 the #i9 tool0
- F &al&ulation of load &olle&ti6es for gear'oC and dri6etrain, e0 g0 to de6elo5 and test measures for safe)guarding of the dri6etrain &om5onents0
- . /' & F of the &ontrol soft)8are on the =C0



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A t75i&al use &ase of the #i9 tool is sho8n in :ig0 70 %he test &ase generator %est . ea6er GIH has found a s&enario 8here the &ontrol soft8are of a transmission 5erforms a di6ision '7 @ero0 %his is &learl7 a 'ug0 %he user re5la7s the re&orded s&enario, 8ith *i)&rosoft >isual #tudio atta&hed to the #i9 tool0 . hen the di6ision '7 @ero o&&urs, the de'ugger 5o5s u5 as sho8n in the figure, sho8ing the line in the &ontrol)ler sour&e &ode that &auses the eC&e5tion0

*ain &ost fa&tors of using the simulation)'ased tool &hain for automoti6e soft8are de6elo5ment are

- F (ere is 8here modern modeling languages and tools su&h as *odeli&a and #imulation< hel5 redu&e &osts '7 reuse of &om5onents and eas7 5arameteri@ation
- & to kee5 su&h a model u5 to date 8ith the 5lant simulatedF #imulation< allo8s &ontinuous enhan&e)ments 'ased on eCisting models and li'raries '7 re5la&ing &om5onents and models of 6ar7ing &om5leCit7 throughout all de6elo5)ment 5hases0 Reusing models in&luding all interfa&es ne&essar7 for &ali'ration in &om)'ination 8ith a 8ide range of tool o5tions, e0 g0 >ariants . i@ard, CD*)s&ri5ting or o5)timi@ation tools, leads to an in&reasing effi)&ien&7 in the 8orkflo80
- 0 F . ith the introdu&tion of the #il6er ,asi& #oft8are 5a&kage, this effort is signi)fi&antl7 redu&ed0

Des5ite &ontinuing &ost)redu&tion efforts, these in)6estments are still signifi&ant0

%he7 are &om5ensated '7 the 'enefits of su&h a #oft)8are in the 9oo5 setu5 for de6elo5ing &ontrol soft)8are, namel7

- 1 F due to &omforta'le integration of soft8are and 6ehi&le &om5onents on the =C of the de)6elo5er0 %his hel5s to dete&t 5ro'lems earl70
- 1 & , e0 g0 8ith *i&rosoft >isual #tudio De'ugger or $%roni& %est . ea6er G1,2,3,"H0 :ound 5ro')lems &an 'e eCa&tl7 re5rodu&ed as often as needed0
- 2 F A #i9 &onfiguration &an easil7 'e du5li&ated at lo8 &ost0 %his 8a7, e6er7 mem'er of a team &an use its 5ersonal J6irtualJ de6elo5ment en6ir)onment 2! hours a da7, 8ithout 'lo&king rare resour&es like (i9 test rigs, or 5h7si&al 5rotot75es0
- s 34F All mem)'ers of a team eC&hange 8orking results '7 eC&hanging &om5iled modules AD99sB, not sour&es0 %his hel5s to 5rote&t intelle&tual 5ro5ert70
- 1 & F Dur #i9 runs modules Asimulation models, &ontrol soft8areB de6elo5ed using

6er7 different tools 8ithout a&&essing these tools0 %his greatl7 redu&es the &om5leCit7 of the #i9 setu5s Ano tool &ou5lingB0

. e 5resented the tool &hain used '7 Daimler for simulation)'ased de6elo5ment of transmission &on)trol soft8are0 %he en6ironment is 'ased on * odel)i&a, 5ro6ides 'uild)in su55ort for automoti6e stand)ards, im5orts 6ehi&le models 6ia the standard : * - and uses these models to 5erform &losed)loo5 simu)lation of automoti6e &ontrol soft8are0 %he 6irtual de)6elo5ment en6ironment &reated this 8a7 hel5s to shorten de6elo5ment &7&les, eases test and de'ug)ging, hel5s to 5aralleli@e and hen&e to s5eed u5 de)6elo5ment and 5ro6ides a &on6enient 5latform for &olla'oration 'et8een DaimlerJs transmission de6el)o5ment de5artments and its su55liers and engineer)ing ser6i&e 5ro6iders0

Dur 8ork on the : * - GIH 5resented here has 'een funded '7 the :ederal * inistr7 for Edu&ation and #&ien&e A , * , :B 8ithin the -%EA2 5ro3e&t * DDE9)-#AR A:Krderkenn@ei&hen 01-#0I002B0

G1H A0 Rink, E0 Chrisofakis, * 0 %atarF Automating %est of Control #oft8are) * ethod for Auto)mati& %estGeneration0 A%Lelektronik "?200+ >olume !, 550 2!)270

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