

OMO: Software cost estimation

Tim Menzies

Lane Department of Computer Science, West Virginia University, PO Box 6109, Morgantown, WV, 26506-6109, USA;
http://tim.menzies.us; tim@menzies.us

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Abstract COCOMO is a software effort estimation tool. OMO is COCOMO written in SWI-Prolog [5]

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1 Warning!!!

Contains deliberate error. Output should be:

```
COCOMO.ga says 1223.53 months (total);
28 staff over 45 months
```

But show how that is all broken.

```
COCOMO.ga says 134588.0 months (total);
547 staff over 247 months
```

What is wrong?

2 What is COCOMO?

The COCOMO project aims at developing an open-source, public-domain software effort estimation model. The project has collected information on 161 projects from commercial, aerospace, government, and non-profit organizations [1, 4]. As of 1998, the projects represented in the database were of size 20 to 2000 KSLOC (thousands of lines of code) and took between 100 to 10000 person months to build.

COCOMO measures effort in calendar months where one month is 152 hours (and includes development and management hours). The core intuition behind COCOMO-based estimation is that as systems grow in size, the effort required to create them grows exponentially, i.e. $effort \propto KSLOC^x$. More precisely:

$$months = a * \left(KSLOC^{(0.91 + \sum_{i=1}^5 SF_i)} \right) * \left(\prod_{j=1}^{17} EM_j \right)$$

where a is a domain-specific parameter, and KSLOC is estimated directly or computed from a function point analysis. SF_i are the scale factors (e.g. factors such as “have we built this kind of system before?”) and EM_j are the cost drivers (e.g. required level of reliability). Figure 1 lists the scale drivers and effort multipliers.

Software effort-estimation models like COCOMO-II should be tuned to their local domain. Off-the-shelf “untuned” models have been up to 600% inaccurate in their estimates, e.g. [3, p165] and [2]. However, tuned models can be far more accurate. For example, [1] reports a study with a bayesian

Type	Acronym	Definition	Low-end	Medium	High-end
EM	acap	analyst capability	worst 15%	55%	best 10%
EM	aexp	applications experience	2 months	1 year	6 years
SF	arch	architecture or risk resolution	few interfaces defined or few risk eliminated	most interfaces defined or most risks eliminated	all interfaces defined or all risks eliminated
EM	cplx	product complexity	e.g. simple read/write statements	e.g. use of simple interface widgets	e.g. performance-critical embedded systems
EM	data	database size (DB bytes/ Program SLOC)	10	100	1000
EM	docu	documentation	many life-cycle phases not documented		extensive reporting for each life-cycle phase
SF	flex	development flexibility	development process rigorously defined	some guidelines, which can be relaxed	only general goals defined
EM	ltex	language and tool-set experience	2 months	1 year	6 years
EM	pcap	programmer capability	worst 15%	55%	best 10%
EM	pcon	personnel continuity (% turnover per year)	48%	12%	3%
EM	pexp	platform experience	2 months	1 year	6 years
SF	pmat	process maturity	CMM level 1	CMM level 3	CMM level 5
SF	prec	precedentedness	we have never built this kind of software before	somewhat new	thoroughly familiar
EM	pvol	platform volatility (<i>frequency of major changes</i>) (<i>frequency of minor changes</i>)	$\frac{12 \text{ months}}{1 \text{ month}}$	$\frac{6 \text{ months}}{2 \text{ weeks}}$	$\frac{2 \text{ weeks}}{2 \text{ days}}$
EM	rely	required reliability	errors mean slight inconvenience	errors are easily recoverable	errors can risk human life
EM	ruse	required reuse	none	across program	across multiple product lines
EM	sced	dictacted development schedule	deadlines moved closer to 75% of the original estimate	no change	deadlines moved back to 160% of the original estimate
EM	site	multi-site development	some contact: phone, mail	some email	interactive multi-media
EM	stor	main storage constraints (% of available RAM)	N/A	50%	95%
SF	team	team cohesion	very difficult interactions	basically co-operative	seamless interactions
EM	time	execution time constraints (% of available CPU)	N/A	50%	95%
EM	tool	use of software tools	edit,code,debug		well intergrated with lifecycle

Fig. 1 Parameters of the COCOMO-II effort risk model; adapted from http://sunset.usc.edu/COCOMOII/expert_cocomo/drivers.html. “Stor” and “time” score “N/A” for low-end values since they have no low-end defined in COCOMO-II. “SF” denotes “scale factors” and “EM” denotes “effort multipliers”.

tuning algorithm using the COCOMO project database. After bayesian tuning, a cross-validation study showed that COCOMO-II model produced estimates that are within 30% of the actuals, 69% of the time.

Figure 2 shows the sizes of various COCOMO tuning parameters. Notice the linear fits of the top two tunings: these were generated via linear regression and hence are straight lines. The bottom row shows tunings generated from a genetic algorithm (GA): such GAs were designed to handle non-linear situations so their curve fits can be all over the place.

The intuition to be gained from Figure 2 is that some COCOMO parameters are more influential than others. Some are weakly correlated to increasing effort (column 1); some are weakly correlated to decreasing effort (column 2); and some are strongly correlated to decreasing effort (column 3). This will be useful later when we write search engines to control COCOMO. A core heuristic will be “change the influential parameters first”.

The last column of Figure 2 relate to the effort multipliers. While shown here as linear, their influence can be even greater than that since they are used up in an exponential equation.

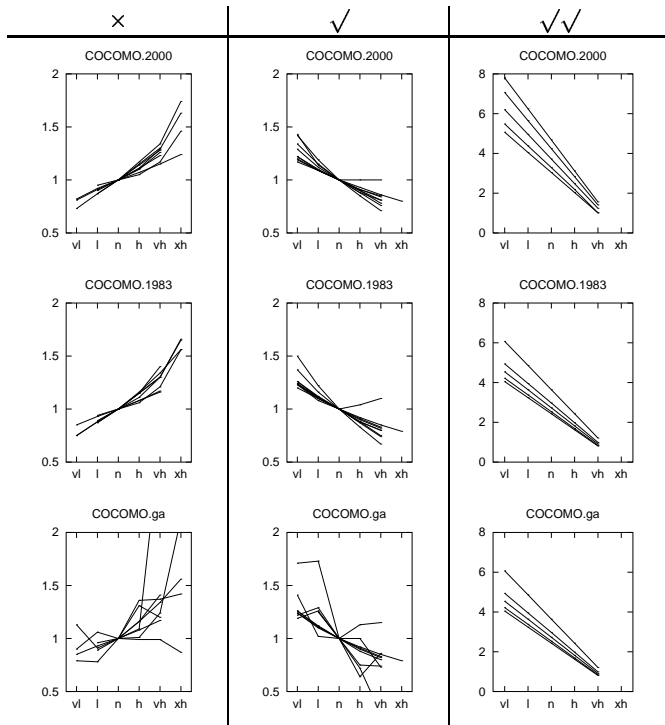


Fig. 2 Influence of different COCOMO parameters

3 Installation

```

1 :- load_files([lib % grab standard stuff
2             ,cfg % options controller
3             ,gpl0, gpl1 % GPL-2 license stuff
4             ,omo0 % pre-load actions
5             ,omolib % local libraries
6             ,omol % predicates
7             ,omo2 % start-up commands
8             ,omokb1 % example project file
9             ,ufp2sloc % function points per LOC database
10            ],[silent(yes),if(changed)]).

```

4 Pre-load actions

4.1 Hooks

Fast assertions of named variables.

```

11 term_expansion((X;Y :- Z),Out) :-
12     multis((X;Y) :- Z),Out).

```

Instantiate named fields

```

13 term_expansion(Functor is Fields,Out) :-
14     fields(Fields,Functor,Out).

```

5 Main System

5.1 Main driver

```

15 estimate :-
16     cocomo(Coc),
17     estimate(Pm,Staff,Months),
18     format('COCOMO.~p says ~p months (total);',[Coc,Pm]),
19     format('~p staff over ~p months\n',[Staff,Months]).
20
21 estimate(Pm,Staff,Months) :-
22     tdev(Tdev),
23     pm(Pm0),
24     Pm is Pm0,
25     Staff is ceiling(Pm/Tdev),
26     Months is ceiling(Tdev),
27     !.

```

5.2 Equations

5.2.1 Sizing equations

```

28 size((1 + (R/100)) * (N + E)) :-
29     revl(R), newKsloc(N), equivalentKsloc(E).
30
31 equivalentKsloc(Ak*Aam*(1-(At/100))) :-
32     adaptedKsloc(Ak), at(At), aam(Aam).
33
34 aam(Am) :- aaf(Af), compare(C,Af,50), aaml(C,Af,Am).
35
36 aaml(=,Af, X) :- aaml(<,Af,X).
37 aaml(>,Af, (Aa+Af+(Su*U))/100) :- aa(Aa),su(Su),unfm(U).
38 aaml(<,Af, (Aa+Af*(1+(0.02*Su*U))/100)) :-
39     aa(Aa), su(Su), unfm(U).
40
41 aaf(0.4*Dm+0.3*cm+0.3*Im) :- dm(Dm), cm(Cm), im(Im).

```

5.2.2 Schedule Equations

```

42 tdev((C*(P^F))*SP/100) :-
43     c(C), pmNs(P), f(F), scedPercent(SP).
44
45 f( D + 0.2*(E-B) ) :-
46     d(D),e(E), b(B).

```

5.2.3 Effort Equations

```

47 hmmm... sced value never used
48 pm(Pm0*Em17+Pa) :-
49     pmNs(Pm0), w(sced,Em17), pmAuto(Pa).
50
51 pmNs(A*S*(S^E)*Em1 *Em2 *Em3 *Em4 *Em5 *Em6 *Em7*Em8*Em9*
52     Em10*Em11*Em12*Em13*Em14*Em15*Em16) :-
53     a(A), size(S), e(E), w(rely,Em1), w(data,Em2),
54     w(cplx,Em3), w(ruse,Em4), w(docu,Em5), w(time,Em6),
55     w(stor,Em7), w(pvol,Em8), w(acap,Em9), w(pcap,Em10),
56     w(pcon,Em11),w(aexp,Em12),w(pexp,Em13),
57     w(ltex,Em14),w(tool,Em15),w(site,Em16).
58
59 e(B + 0.01*(Sf1+Sf2+Sf3+Sf4+Sf5)) :-
60     b(B),
61     w(prec,Sf1), w(flex,Sf2),w(arch,Sf3),
62     w(team,Sf4), w(pmat,Sf5).
63
64 pmAuto((Ak*(At/100))/Ap) :-
65     adaptedKsloc(Ak), at(At), atKprod(Ap).

```

5.3 Tunings

5.3.1 Constants

```

66 a(2.5) :- cocomo(1983).
67 a(2.94) :- cocomo(2000).
68 a(2.94) :- cocomo(ga).
69
70 b(0.91) :- cocomo(2000).
71 b(1.01) :- cocomo(1983).
72 b(1.01) :- cocomo(ga).
73
74 c(3.0) :- cocomo(1983).
75 c(3.67) :- cocomo(2000).
76 c(3.67) :- cocomo(ga).
77
78 d(0.28) :- cocomo(2000).
79 d(0.33) :- cocomo(1983).
80 d(0.33) :- cocomo(ga).

```

5.3.2 Post-architecture scale factors The COCOMO 2000 scale factors learnt via bayesian tuning.

```

81 postArch(2000,scaleFactors) =
82     [ xl, vl, l, n, h, vh, xh]+
83     [[prec, 6.20,4.96,3.72,2.48,1.24, _]
84     ,[flex, 5.07,4.05,3.04,2.03,1.01, _]
85     ,[arch, 7.07,5.65,4.24,2.83,1.41, _]
86     ,[team, 5.48,4.38,3.29,2.19,1.01, _]
87     ,[pmat, 7.80,6.24,4.68,3.12,1.56, _]
88     ].

```

The original scale factors.

```

89 postArch(1983,scaleFactors) =
90     [ xl, vl, l, n, h, vh, xh]+
91     [[prec, 4.05,3.24,2.43,1.62,0.81, _]
92     ,[flex, 6.07,4.86,3.64,2.43,1.21, _]
93     ,[arch, 4.22,3.38,2.53,1.69,0.84, _]
94     ,[team, 4.94,3.95,2.97,1.98,0.99, _]
95     ,[pmat, 4.54,3.64,2.73,1.82,0.91, _]
96     ].

```

Some scale factors learnt via some genetic algorithms.

```

97 postArch(ga,scaleFactors) =
98     [ xl, vl, l, n, h, vh, xh]+
99     [[prec, 4.05,3.24,2.43,1.62,0.81, _]
100     ,[flex, 6.07,4.86,3.64,2.43,1.21, _]
101     ,[arch, 4.22,3.38,2.53,1.69,0.84, _]
102     ,[team, 4.94,3.95,2.97,1.98,0.99, _]
103     ,[pmat, 4.54,3.64,2.73,1.82,0.91, _]
104     ].

```

5.3.3 Post-architecture effort multipliers: The COCOMO 2000 effort multipliers learnt via bayesian tuning.

```

105 postArch(2000,effortMultipliers) =
106     [xl, vl, l, n, h, vh, xh]+
107     [[rely, 0.82,0.92,1.00,1.10,1.26, _]
108     ,[data, 0.90,1.00,1.14,1.28, _]
109     ,[cplx, 0.73,0.87,1.00,1.17,1.34,1.74]
110     ,[ruse, 0.95,1.00,1.07,1.15,1.24]
111     ,[docu, 0.81,0.91,1.00,1.11,1.23, _]
112     ,[time, 1.00,1.11,1.29,1.63]
113     ,[stor, 1.00,1.05,1.17,1.46]
114     ,[pvoll, 0.87,1.00,1.15,1.30, _]
115     ,[acap, 1.42,1.19,1.00,0.85,0.71, _]
116     ,[pcap, 1.34,1.15,1.00,0.88,0.76, _]
117     ,[pcon, 1.29,1.12,1.00,0.90,0.81, _]
118     ,[aexp, 1.22,1.10,1.00,0.88,0.81, _]
119     ,[pexp, 1.19,1.09,1.00,0.91,0.85, _]
120     ,[ltex, 1.20,1.09,1.00,0.91,0.84, _]
121     ,[tool, 1.17,1.09,1.00,0.90,0.78, _]
122     ,[site, 1.22,1.09,1.00,0.93,0.86,0.80]
123     ,[sced, 1.43,1.14,1.00,1.00,1.00, _]
124     ].

```

The original effort multipliers.

```

125 postArch(1983,effortMultipliers) =
126     [ xl, vl, l, n, h, vh, xh]+
127     [[rely, 0.75,0.88,1.00,1.15,1.40, _]
128     ,[data, 0.94,1.00,1.08,1.16, _]
129     ,[cplx, 0.75,0.88,1.00,1.15,1.30,1.65]
130     ,[ruse, 0.89,1.00,1.16,1.34,1.56]
131     ,[docu, 0.85,0.93,1.00,1.08,1.17, _]
132     ,[time, 1.00,1.11,1.30,1.66]
133     ,[stor, 1.00,1.06,1.21,1.56]
134     ,[pvoll, 0.87,1.00,1.15,1.30, _]
135     ,[acap, 1.50,1.22,1.00,0.83,0.67, _]
136     ,[pcap, 1.37,1.16,1.00,0.87,0.74, _]
137     ,[pcon, 1.26,1.11,1.00,0.91,0.83, _]
138     ,[aexp, 1.23,1.10,1.00,0.88,0.80, _]
139     ,[pexp, 1.26,1.12,1.00,0.88,0.80, _]
140     ,[ltex, 1.24,1.11,1.00,0.90,0.82, _]
141     ,[tool, 1.20,1.10,1.00,0.88,0.75, _]
142     ,[site, 1.24,1.10,1.00,0.92,0.85,0.79]
143     ,[sced, 1.23,1.08,1.00,1.04,1.10, _]
144     ].

```

Some effort multipliers learnt via some genetic algorithms.

```

145 postArch(ga,effortMultipliers) =
146     [ xl, vl, l, n, h, vh, xh]+
147     [[rely, 0.79,0.78,1.00,1.16,1.41, _]
148     ,[data, 0.96,1.00,1.31,1.20, _]
149     ,[cplx, 0.90,1.06,1.00,0.99,0.99,0.87]
150     ,[ruse, 0.89,1.00,1.16,1.34,1.56]
151     ,[docu, 0.85,0.93,1.00,1.08,1.17, _]
152     ,[time, 1.00,1.01,1.24,2.13]
153     ,[stor, 1.00,1.36,1.37,1.42]
154     ,[pvoll, 1.25,1.00,1.13,1.15, _]
155     ,[acap, 1.19,1.26,1.00,1.00,0.73, _]
156     ,[pcap, 1.71,1.73,1.00,0.75,0.74, _]
157     ,[pcon, 1.26,1.11,1.00,0.91,0.83, _]
158     ,[aexp, 1.41,1.02,1.00,0.64,0.86, _]
159     ,[pexp, 1.26,1.12,1.00,0.88,0.80, _]
160     ,[ltex, 1.24,1.11,1.00,0.90,0.82, _]
161     ,[tool, 1.13,0.91,1.00,1.09,2.86, _]
162     ,[site, 1.24,1.10,1.00,0.92,0.85,0.79]
163     ,[sced, 1.22,1.29,1.00,0.72,0.29, _]
164     ].

```

5.4 Data dictionary

5.4.1 General

```

165 languageP(X) :- upf2sloc(X,_).
166
167 sym(X) :- rsym(X).
168
169 onezeroP(X) :- rin(0,1,0.2,X), number(X).
170
171 percentP(X) :- rin(0,100,1,X), integer(X).
172
173 posint(X) :- rin(0,65536,X), integer(X).
174 posnum(X) :- rin(0,inf,X), number(X).
175
176 numl0(X) :- rin(0,10,X), number(X).
177
178 cocomoP(2000).
179 cocomoP(1983).
180 cocomoP(ga).
181
182 vlvh(n). vlvh(l). vlvh(h). vlvh(vl). vlvh(vh).
183
184 lvh(n). lvh(l). lvh(h). lvh(vh).
185
186 vlxh(n). vlxh(l). vlxh(h).
187 vlxh(vl). vlxh(vh). vlxh(xh).
188
189 lxx(n). lxx(l). lxx(h). lxx(vh). lxx(xh).
190
191 nxx(n). nxx(h). nxx(vh). nxx(xh).

```

5.4.2 "project"

```

192 (cocomo(Coc); label(L); language(Lan)
193 ;revl(R); newKsloc(K)
194 ;adaptedKsloc(A);cm(C);dm(D);im(I);aa(Aa);unfm(U)
195 ;su(Su);at(At);atKprod(Atp);scedPercent(Sc)
196 ) :-
197   project(Coc,L,Lan,R,K,A,C,D,I,Aa,U,Su,At,Atp,Sc),
198
199   cocomoP(Coc),
200   sym(L), languageP(Lan), percentP(R), percentP(K),
201   posint(A), percentP(C), percentP(I), percentP(Aa),
202   onezeroP(U), percentP(Su),percentP(At),
203   posnum(Atp),posint(Sc),!.

```

5.4.3 "scores"

```

204 (s(prec,Prec);s(flex,Flex);s(arch,Arch)
205 ;s(team,Team);s(pmat,Pmat);s(rely,Rely)
206 ;s(data,Data);s(cplx,Cplx);s(ruse,Ruse)
207 ;s(docu,Docu);s(time,Time);s(stor,Stor)
208 ;s(pvol,Pvol);s(acap,Acap);s(pcap,Pcap)
209 ;s(pcon,Pcon);s(aexp,Aexp);s(pexp,Pexp)
210 ;s(ltex,Ltex);s(tool,Tool);s(site,Site);s(sced,Sced)
211 ):-
212   scores(Prec,Flex,Arch,Team,Pmat,Rely,Data,Cplx,
213   Ruse,Docu,Time,Stor,Pvol,Acap,Pcap,Pcon,
214   Aexp,Pexp,Ltex,Tool,Site,Sced),
215
216   vlvh(Prec), vlvh(Flex), vlvh(Arch), vlvh(Team),
217   vlvh(Pmat), vlvh(Rely), vlvh(Data), vlvh(Cplx),
218   vlvh(Ruse), vlvh(Docu), vlvh(Time), vlvh(Stor),
219   vlvh(Pvol), vlvh(Acap), vlvh(Pcap), vlvh(Pcon),
220   vlvh(Aexp), vlvh(Pexp), vlvh(Ltex), vlvh(Tool),
221   vlvh(Site),!.

```

6 Start-up actions

Usual stuff.

```

222 :- sneak(
223   ['defaults.omo' % see Figure ??
224   , 'config.omo' % see Figure ??
225   , ufp2sloc % see §??
226   ]).
227
228 :- commandLine.
229 :- ?verbose -> hello ; true.

```

7 OMO Support code

7.1 Multis/2

Fast, named, assertions

```

230 multis(Stuff,All) :-
231   bagof(One,Stuff^multi(Stuff,One),All).
232
233 multi((Heads :- Tail),(Head :- Tail) :-
234   d2l(Heads,List),
235   member(Head,List).

```

7.2 Fields/3

Poke some values into the named fields.

```

236 fields(Fields,Func,Term) :- fields1(Fields,Func,Term),!.
237 fields(_,_,[]).
238
239 fields1([],_,-).
240 fields1([Field|Fields],Func,Term) :-
241   fields2(Field,Func,Term),
242   fields1(Fields,Func,Term).
243
244 fields2(Field,Func,Term) :-
245   clause(Field,(Term,_)),
246   functor(Term,Func,_),!.
247 fields2(Field,Func,_) :-
248   barph(badField(Func is [Field])).

```

7.3 w/2

Convert scores to numeric weights

```

249 w(A,W) :-
250   demand(s(A,S)),
251   postArch(A,S,W),
252   demand(num10(W)).
253
254 postArch(A,S,W) :-
255   cocomo(When),
256   lookUp(postArch(When,_),A,S,W).

```

7.4 Random types

7.4.1 Random strings

```

257 rsym(X) :- nonvar(X),!.
258 rsym(X) :- gensym(g,X).
259
260 rsym(_),X :- nonvar(X),!.
261 rsym(A,X) :- gensym(A,X).

```

7.4.2 Random number within a range

```

262 rin(M,N,_X) :- nonvar(X),!, number(X),M <= X, X <= N.
263 rin(M,N,O,X) :- Steps is integer((N-M)/O),
264   between(1,Steps,_),
265   Y is random(Steps+1),
266   X is min(M + Y*O,N).

```

7.4.3 Random value of a list

```

267 rin(M,N,X) :- nonvar(X),!, number(X),M <= X, X <= N.
268 rin(M,N,X) :- Steps is integer(N-M),
269   between(1,Steps,_),
270   Y is random(Steps+1),
271   X is min(M + Y,N).
272
273 rin(X,L) :- number(X),!, member(Y,L), X == Y.
274 rin(X,L) :- nonvar(X),!, member(X,L).
275 rin(X,L) :- length(L,N), rmember1(L,N,X).
276
277 rmember1([H|_],H) :- !.
278 rmember1([H|T],N,X) :- Pos is random(N) + 1,
279   less1(Pos,[H|T],Y,L),
280   (X=Y
281   ; N1 is N - 1,
282   rmember1(L,N1,X)).

```

8 Knowledge base

8.1 Sample project

```

283 scores is [s(pmat,v1)
284   ,s(pvol,1)
285   ,s(ltex,1)
286   ].
287
288 project is [cocomo(ga)
289   ,label('eg#1')
290   ,language(prolog)
291   ,revl(10)
292   ,newKsloc(100)
293   ,adaptedKsloc(0)
294   ,cm(0) % new code
295   ,dm(0) % new code
296   ,im(0) % new code
297   ,aa(2) % basic module search + docu [4, p24]
298   ,unfm(0.4) % somewhat familiar
299   ,su(30) % nominal value [4, p23]
300   ,at(0)
301   ,atKprod(2.4)
302   ,scedPercent(100)
303   ].

```

8.2 LOC per Function points

Also loaded, but not shown due to size, are tables showing productivity in different 482 different programming systems. It tables a *lot* of code to get anything done in binary, but less code as the language matures. So:

```
upf2sloc('1st generation default',320).
upf2sloc('2nd generation default',107).
upf2sloc('3rd generation default',80).
upf2sloc('4th generation default',20).
upf2sloc('5th generation default',5).
```

The units here are lines of code per function point. For more details, see Boehm.

9 Bugs

None known but many suspected.

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