memo9@.ai.wvu.2003. Available from http://tim.menzies.com/pdf/03omo.pdf

OMO: Software cost estimation

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Abstract COCOMO is a software effort estimation tool. OMO is COCOMO written in SWI-Prolog [16]

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1 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 [1,15]. 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:

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

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. [14, p165] and [2]. However, tuned models can be far more accurate. For example, [1] reports a study with a bayesian 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

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 $(\frac{frequency\ of\ major\ changes}{frequency\ of\ minor\ changes})$	$\frac{12\ months}{1\ month}$	$\frac{6\ months}{2\ weeks}$	$\frac{2\ weeks}{2\ days}$
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".

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.

2 Requires

```
:- load_files([lib        % grab standard stuff [10]
              ,cfg        % options controller [11]
              ,gpl0, gpl1 % GPL-2 license stuff [7]
              ,omo0       % pre-load actions
              ,omolib     % local libraries
              ,omo1       % predicates
              ,omo2       % start-up commands
              ,ufp2sloc   % function points per LOC database
              ],[silent(yes),if(changed)]).
```

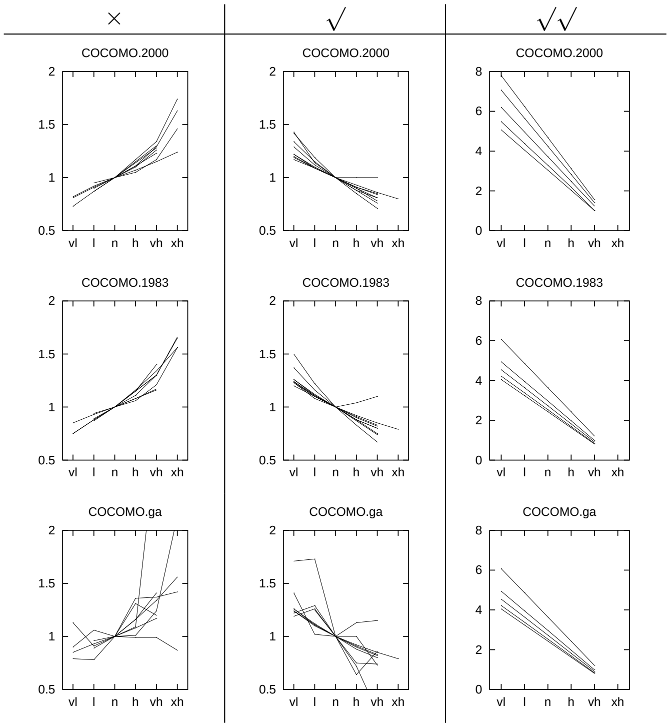

Fig. 2 Influence of different COCOMO parameters

3 Pre-load actions

3.1 Operators

Something to mark decisions we are considering

```
:- op(1,xf,?).
```

Something to mark range declarations.

```
:- op(701,xfx,of).
```

3.2 Flags

```
:- discontiguous (of/3),(range/3),(goal/2).
:- dynamic (of/3),(range/3),(goal/2).
```

3.3 Hooks

Define some expected value, and its associated range predicate.

```
term_expansion(X of Y,Z) :- ofs(X of Y,Z).
```

4 Main System

4.1 Main driver

```

estimate :- project := P, estimate(P).

estimate(P) :-
    getProject(P),
    cocomo(Coc),
    estimate(Pm,Staff,Months),
    format('COCOMO.~p says ~p months (total);',[Coc,Pm]),
    format('~p staff over ~p months\n', [Staff,Months]).

estimate(Pm,Staff,Months) :-
    tdev(Tdev),
    pm(Pm0),
    Pm is Pm0,
    Staff is ceiling(Pm/Tdev),
    Months is ceiling(Tdev),
    !.
```

4.2 Equations

4.2.1 Sizing equations

```
size((1 + (R/100)) *(N + E)) :-
    revl(R), newKsloc(N), equivalentKsloc(E).

equivalentKsloc(Ak*Aam*(1-(At/100))) :-
    adaptedKsloc(Ak), at(At), aam(Aam).

aam(Am) :- aaf(Af), compare(C,Af,50), aam1(C,Af,Am).

aam1(=,Af, X) :- aam1(<,Af,X).
aam1(>,Af, (Aa+Af*(Su*U))/100) :- aa(Aa),su(Su),unfm(U).
aam1(<,Af,((Aa+Af*(1+(0.02*Su*U)))/100)) :-
    aa(Aa), su(Su), unfm(U).

aaf(0.4*Dm+0.3*Cm+0.3*Im) :- dm(Dm), cm(Cm), im(Im).
```

4.2.2 Schedule Equations

```
tdev((C*(P^F))*SP/100) :-
    c(C), pmNs(P), f(F), scedPercent(SP).

f( D + 0.2*(E-B))  :-
    d(D),e(E), b(B).
```

4.2.3 Effort Equations

hmmm... sced value never used

```
pm(Pm0*Em17+Pa) :-
    pmNs(Pm0), w(sced,Em17), pmAuto(Pa).

pmNs(A*(S^E)*Em1 *Em2 *Em3 *Em4 *Em5 *Em6 *Em7*Em8*Em9*
            Em10*Em11*Em12*Em13*Em14*Em15*Em16) :-
    a(A), size(S), e(E), w(rely,Em1), w(data,Em2),
    w(cplx,Em3), w(ruse,Em4), w(docu,Em5), w(time,Em6),
    w(stor,Em7), w(pvol,Em8), w(acap,Em9), w(pcap,Em10),
    w(pcon,Em11),w(aexp,Em12),w(pexp,Em13),
    w(ltex,Em14),w(tool,Em15),w(site,Em16).

e(B + 0.01*(Sf1+Sf2+Sf3+Sf4+Sf5)) :-
    b(B),
    w(prec,Sf1), w(flex,Sf2),w(arch,Sf3),
    w(team,Sf4), w(pmat,Sf5).

pmAuto((Ak*(At/100))/Ap) :-
    adaptedKsloc(Ak), at(At), atKprod(Ap).
```

4.3 Tunings

4.3.1 Constants

```
a(2.5)  :- cocomo(1983).
a(2.94) :- cocomo(2000).
a(2.94) :- cocomo(ga).

b(0.91) :- cocomo(2000).
b(1.01) :- cocomo(1983).
b(1.01) :- cocomo(ga).

c(3.0)  :- cocomo(1983).
c(3.67) :- cocomo(2000).
c(3.67) :- cocomo(ga).

d(0.28) :- cocomo(2000).
d(0.33) :- cocomo(1983).
d(0.33) :- cocomo(ga).
```

4.3.2 *Post-architecture scale factors*

The COCOMO 2000 scale factors learnt via bayesian tuning.

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

The original scale factors.

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

aa :- expand_term(postArch(1983,scaleFactors) has
           [ xl,  vl,   l,   n,   h,  vh, xh]+
    [[prec,   _,4.05,3.24,2.43,1.62,0.81,  _]
    ,[flex,   _,6.07,4.86,3.64,2.43,1.21,  _]],
    L),
    writes(L).
```

Some scale factors learnt via some genetic algorithms.

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

4.3.3 *Post-architecture effort multipliers:*

The COCOMO 2000 effort multipliers learnt via bayesian tuning.

```
postArch(2000,effortMultiplers) has
           [xl,   vl,   l,   n,  h,  vh,  xh]+
    [[rely,  _,0.82,0.92,1.00,1.10,1.26,   _]
    ,[data,  _,_   ,0.90,1.00,1.14,1.28,   _]
    ,[cplx,  _,0.73,0.87,1.00,1.17,1.34,1.74]
    ,[ruse,  _,_   ,0.95,1.00,1.07,1.15,1.24]
    ,[docu,  _,0.81,0.91,1.00,1.11,1.23,   _]
    ,[time,  _,   _,   _,1.00,1.11,1.29,1.63]
    ,[stor,  _,   _,   _,1.00,1.05,1.17,1.46]
    ,[pvol,  _,   _,0.87,1.00,1.15,1.30,   _]
    ,[acap,  _,1.42,1.19,1.00,0.85,0.71 ,  _]
    ,[pcap,  _,1.34,1.15,1.00,0.88,0.76,   _]
    ,[pcon,  _,1.29,1.12,1.00,0.90,0.81,   _]
    ,[aexp,  _,1.22,1.10,1.00,0.88,0.81,   _]
    ,[pexp,  _,1.19,1.09,1.00,0.91,0.85,   _]
    ,[ltex,  _,1.20,1.09,1.00,0.91,0.84,   _]
    ,[tool,  _,1.17,1.09,1.00,0.90,0.78,   _]
    ,[site,  _,1.22,1.09,1.00,0.93,0.86,0.80]
    ,[sced,  _,1.43,1.14,1.00,1.00,1.00,   _]
    ].
```

The original effort multipliers.

```
postArch(1983,effortMultiplers) has
           [ xl,  vl,   l,   n,   h,  vh,  xh]+
    [[rely,   _,0.75,0.88,1.00,1.15,1.40,   _]
    ,[data,   _,   _,0.94,1.00,1.08,1.16,   _]
    ,[cplx,   _,0.75,0.88,1.00,1.15,1.30,1.65]
    ,[ruse,   _,   _,0.89,1.00,1.16,1.34,1.56]
    ,[docu,   _,0.85,0.93,1.00,1.08,1.17,   _]
    ,[time,   _,   _,   _,1.00,1.11,1.30,1.66]
    ,[stor,   _,   _,   _,1.00,1.06,1.21,1.56]
    ,[pvol,   _,   _,0.87,1.00,1.15,1.30,   _]
    ,[acap,   _,1.50,1.22,1.00,0.83,0.67,   _]
    ,[pcap,   _,1.37,1.16,1.00,0.87,0.74,   _]
    ,[pcon,   _,1.26,1.11,1.00,0.91,0.83,   _]
    ,[aexp,   _,1.23,1.10,1.00,0.88,0.80,   _]
    ,[pexp,   _,1.26,1.12,1.00,0.88,0.80,   _]
    ,[ltex,   _,1.24,1.11,1.00,0.90,0.82,   _]
    ,[tool,   _,1.20,1.10,1.00,0.88,0.75,   _]
    ,[site,   _,1.24,1.10,1.00,0.92,0.85,0.79]
    ,[sced,   _,1.23,1.08,1.00,1.04,1.10,   _]
    ].
```

Some effort multipliers learnt via some genetic algorithms.

```
postArch(ga,effortMultiplers) has
            [ xl,  vl,   l,   n,   h,  vh,  xh]+
    [[rely,    _,0.79,0.78,1.00,1.16,1.41,   _]
    ,[data,    _,   _,0.96,1.00,1.31,1.20,   _]
    ,[cplx,    _,0.90,1.06,1.00,0.99,0.99,0.87]
    ,[ruse,    _,   _,0.89,1.00,1.16,1.34,1.56]
    ,[docu,    _,0.85,0.93,1.00,1.08,1.17,   _]
    ,[time,    _,   _,   _,1.00,1.01,1.24,2.13]
    ,[stor,    _,   _,   _,1.00,1.36,1.37,1.42]
    ,[pvol,    _,   _,1.25,1.00,1.13,1.15,   _]
    ,[acap,    _,1.19,1.26,1.00,1.00,0.73,   _]
    ,[pcap,    _,1.71,1.73,1.00,0.75,0.74,   _]
    ,[pcon,    _,1.26,1.11,1.00,0.91,0.83,   _]
    ,[aexp,    _,1.41,1.02,1.00,0.64,0.86,   _]
    ,[pexp,    _,1.26,1.12,1.00,0.88,0.80,   _]
    ,[ltex,    _,1.24,1.11,1.00,0.90,0.82,   _]
    ,[tool,    _,1.13,0.91,1.00,1.09,2.86,   _]
    ,[site,    _,1.24,1.10,1.00,0.92,0.85,0.79]
    ,[sced,    _,1.22,1.29,1.00,0.72,0.29,   _]
    ].
```

4.4 *Data dictionary*

4.4.1 *General*

```
languageP(X) :- upf2sloc(X,_).

sym(X) :- rsym(X).

onezeroP(X) :- rin(0,1,0.2,X), number(X).

percentP(X) :- rin(0,100,1,X),integer(X).

posint(X)   :- rin(0,65536,X),integer(X).
posnum(X)   :- rin(0,inf,X),number(X).

num10(X) :- rin(0,10,X), number(X).

cocomoP(2000).
cocomoP(1983).
cocomoP(ga).

vlvh(n). vlvh(l). vlvh(h). vlvh(vl). vlvh(vh).

lvh(n). lvh(l). lvh(h). lvh(vh).

vlxh(n).  vlxh(l).  vlxh(h).
vlxh(vl). vlxh(vh). vlxh(xh).

lxh(n). lxh(l). lxh(h). lxh(vh). lxh(xh).

nxh(n). nxh(h). nxh(vh). nxh(xh).
```

4.4.2 *Specifics*

Declare what ranges are appropriate for what variables.

```
cocomo       of cocomoP.    label        of sym.
language     of languageP.  revl         of percentP.
newKsloc     of percentP.   adaptedKsloc of posint.
cm           of percentP.   dm           of percentP.
im           of percentP.   aa           of percentP.
unfm         of onezeroP.   su           of percentP.
at           of percentP.   atKprod      of posnum.
scedPercent  of percentP.

prec of vlvh.  flex of vlvh. arch of vlvh.
team of vlvh.  pmat of vlvh. rely of vlvh.
data of lvh.   cplx of vlxh. ruse of lxh.
docu of vlvh.  time of nxh.  stor of nxh.
pvol of lvh.   acap of vlvh. pcap of vlvh.
pcon of vlvh.  aexp of vlvh. pexp of vlvh.
ltex of vlvh.  tool of vlvh. site of vlxh.
sced of vlvh.
```

5 OMO Support code

5.1 `GetProject/1` *zaps old project knowledge*

Definitions of assertions created when projects are loaded.

```
defProj(range(_,_,_)).
defProj(option(X,_)) :- of(X,_,_).
defProj(goal(_,_)).

getProject(X) :-
    proj0,           % project details now dynamic
    projReset,       % zap old details
    [X],             % load projects details
    readies(Items), % find side-effects
    forall(member(One,Items),
           getProject1(One)).

getProject1((:- X)) :- !,X.
getProject1(X) :- assert(X).
```

Support code for the above:

```
proj0 :- all
         defProj(T),
     functor(T,F,A),
     dynamic(F/A),
     discontiguous(F/A).

projReset :-
    all defProj(T), (retract(T); retract((T :- _))).
```

5.2 *Defining expected variables.*

The assertion "**`Var of Pred.`**" gives OMO the expectation that the predicate **`Pred(Value)`** can be used to check supplied values for **`Var`**. Alternatively, if none are generated, then **`Pred(Value)`** can be used to generate a value for **`Var`**.

Internally, "**`Var of Pred.`**" is stored in an **`of/3`** assertion:

```
of(Var,Pred(Value),Value).
```

```
ofs(A,Bs) :-
    bagof(B,A^of1(A,B),Bs).

of1(X of Y,_) :-
    \+ ground(X of Y),
    !,barphln(mustBeLowerCase(X of Y)).
of1(_ of Y,_) :-
    Pred=.. [Y,_],
    \+ clause(Pred,_),
    !,barphln(unknownType(Y)).
of1(X of Y,Out) :-
    Head=.. [X,Value],
    Body=.. [Y,Value],
    (Out=(Head :- range(X,_,Value),Body)
        ;Out=of(X,Body,Value)).
```

General form	Notes	Example
`Var = List?`	**`Var`** can take on the variables in **`List`**. mark all items in **`List`** as goals	**`cplx = [vh,xh]?`**.
`Var=[X1,X2?,X3,..]`	**`Var`** can take any of the variables in the list. Some of these values are goal values.	**`ruse =[l,n,h?].`**
`Var= [X1,X2,X3,..]`	**`Var`** can take any of the variables in the list. None of these values are goal values.	**`time = [n,h,vh].`**
`Var= X?`	**`Var`** can take only take one value. and that value is a goal.	**`pvol = h?.`**
`Var= ?`	**`Var`** can take any value over its range and all of those values are goals.	**`data = ? .`**
`Var= X`	**`Var`** can take one value and that value is not agoal.	**`pcap = n.`**

Fig. 3 Specifying ranges for variables.

5.3 *Checking supplied variables*

(Assumes **`of/3`** facts has been previously generated).

Users of this system can supply values to be used in the simuation. That input description includes mostly *range* values and a few *goal* values. Simulations backtrack over the *range* of values. Optimizers of this simulation can query the *goal* values to constrain their optimizations to just the *goal*s.

Syntactically, goal values are marked with a question mark (e.g. **`X?`**) and anything not marked in this way is a range value. Figure 3 shows the various forms.

Via a **`term_expansion`**, the **`ready`** assertion triggers the following code;

```
readies(L) :- bagof(X,ready(X),L).
```

For variables with no settings, use the **`of/3`**'s **`Pred`** to get a value.

```
ready((range(X,n,Value) :- Pred)) :-
    of(X,Pred,Value),
    \+ option(X,_).
```

Complain if a variable's setting is illegal.

```
ready((:- burp(badValue(W,Value)))) :-
    of(W,Pred,Value),
    option(W,X),
    once(ready0(X,_,_,Y)),
    member(mark(_,Value),Y), %range,goal,guess
    \+ Pred.
```

Otherwise, generate appropiate **`range`**

```
ready(Out):-
    of(W,Pred,Value),
    option(W,X),
    once(ready0(X,Pred,Value,Y)),
    member(Z,Y),
    ready1(Z,W,Out).
```

```
ready0([H|T]?, _,_,L) :- maplist(ready0aGoal,[H|T],L).
ready0([H|T],  _,_,L) :- maplist(ready0a,[H|T],L).
ready0(Item?,  _,_,[mark(goal,Item)]).
ready0( ?   ,  P,V,[pred(P,V)]).
ready0(Item,   _,_,[mark(range,Item)]).

ready0a(X?,mark(goal,X)).
ready0a(X, mark(guess,X)) :- atomic(X).

ready0aGoal(X,mark(guess,X)).
```

Anything marked as a range generates a **range** fact.

```
ready1(mark(range,Y),   X, range(X,1,Y)).
```

Anything that is a guess is one of the **range**s we want to guess.

```
ready1(mark(guess,Y),   X, range(X,n,Y)).
```

Anything marked as a goal generated a **range** and a **goal** fact.

```
ready1(mark(goal,One), X, range(X,n,One)).
ready1(mark(goal,One), X, goal(X,One)).
```

Anything marked as a goal of unknwon range generates range and goal rules which pull all values from the predicate **P**.

```
ready1(pred(P,V),      X, (range(X,n,V) :- P)).
ready1(pred(P,V),      X, (goal(X,V)  :- P)).
```

5.4 w/2

Convert scores to numeric weights

```
w(A,W) :-
    range(A,_,S),
    postArch(A,S,W),
    num10(W).

postArch(A,S,W) :-
    cocomo(When),
    call(lookUp(postArch(When,_),A,S,W)).
```

6 Knowledge base

6.1 Sample project “eg1”

```
cocomo       = ga.
label        =  ’eg1’.
language     =  prolog.
revl         =  10.
newKsloc     = 100.
adaptedKsloc =   0.
cm           =   0.   % new code
dm           =   0.   % new code
im           =   0.   % new code
aa           =   2.   % basic module search + docu [15, p24]
unfm         =   0.4. % somewhat familiar
su           =  30.   % nom=al value [15, p23]
at           =   0.
atKprod      =   2.4.
scedPercent  = 100.
prec         = [vl,l].
flex         = [l?,n,h,vh].
arch         = [vl,l, n?].
team         = [l, n?].
pmat         = [vl,l,n, h?].
rely         = vh.
data         = n .
cplx         = [vh,xh]? .
ruse         = [l,n,h?].
docu         = [l,n,h?].
time         = [n,h,vh].
stor         = [n?,h,vh].
pvol         = l.
acap         = [l,n?].
pcap         = n.
pcon         = [l,n?].
aexp         = [l,n].
pexp         = [n].
ltex         = [l,n,h?].
tool         = [l,n].
site         = n.
sced         = [vl,l,n?].
```

Important!: all project descriptions have to end with the “**ready.**” assertion.

```
ready.
```

7 Start-up actions

Usual stuff.

```
:- sneak(
        [’defaults.omo’ % see Figure ??
        ,’config.omo’   % see Figure ??
        ,ufp2sloc       % see §??
        ]).

:- commandLine.
:- ?verbose -> hello ; true.
```

8 Bugs

None known but many suspected.

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