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On Program Volume and Program Modularization

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Following [1] and [2] we define for a program $p$:

1. $n_1$ = the number of distinct operators in $p$,
2. $n_2$ = the number of distinct operands in $p$,
3. $N_1$ = the total number of occurrences of operators in $p$,
4. $N_2$ = the total number of occurrences of operands in $p$,
5. $N_p = n_1 + n_2$, the number of distinct basic objects in $p$,
6. $N_p = N_1 + N_2$, the length of the program $p$.

Then the volume $V_p$ of a program $p$ is defined to be:

$$V_p = N_p \log_2 n_p \text{ [bits]}.$$

Program modularization shall be the writing of a program in the form of several nearly independent, only loosely connected pieces. The volume of a program $p$ written as a finite collection $M$ of modules $m$ shall be

$$V_p^M = \sum_{m \in M} V_m = \sum_{m \in M} N_m \log_2 n_m.$$

A modularization $C$ of $p$ shall be called complete iff $|C| > 1$ and

$$\sum_{c \in C} N_c = N_p \text{ and } \sum_{c \in C} n_c = n_p.$$

Then clearly $V_p^C < V_p$ since $V_p^C = \sum_{c \in C} N_c \log_2 n_c < N_p \log_2 n_p = V_p$.

Realistic modularizations $M$ of $p$ will generally not be complete for at least two possible hazards:

H1) $\sum_{m \in M} n_m > n_p$ because of some operators and operands being used in several modules.

H2) $\sum_{m \in M} N_m > N_p$ because of certain necessary additions to the code, e.g., loading base registers, transmitting parameters, etc., when control must be transferred from one module to another.
Although the length of a program may in many cases increase due to modularization, its volume may still decrease. We call a modularization $M$ of $p$ good, whenever $V^M_p < V_p$.

**Guidelines for good Modularizations:**

In trying to obtain good modularizations one should avoid hazards H1) and H2) as far as possible by following certain guidelines. These guidelines have intuitively been known and used for a long time:

G1) Minimize $\sum_{m \in M} e_m$: make the interface between modules, i.e. the set of objects common to several modules - like common global variables, parameters, common procedures, etc. - as simple and small as possible.

G2) Make code expansion due to modularization as small as possible by providing appropriate hardware and software support. This category covers features like:
   a) use of base registers,
   b) simple parameter passing mechanisms,
   c) efficient procedure calls, etc.

**Definition:**

A modularization $O$ of $p$ is called optimal (over the programming language $L$), if $O$ minimizes the volume of $p$, i.e. if for any other modularization $M$ of $p$ (written in $L$) we have:

$$V^O_p \leq V^M_p$$

**Conclusion:**

If the effort $E$ to write a program $p$ is a monotonically increasing function of the volume of $p$, then an optimal modularization of $p$ minimizes the effort to write $p$.

**NOTE:**

An optimally modularized program in a higher level programming language need not give rise to an optimally modularized program in machine language.
Example: Assume we have a program $p$ according to model $A$ of [1] with

$$\eta_p = 180$$
$$N_p = 1040$$

$$V_p = N_p \log_2 \eta_p = 7791$$

a) Incomplete modularization $M$:

Assume we write the program in 5 modules of equal size with an incompleteness factor of $= 10\%$, i.e. using $\eta_i = 40$ and

$$N_i = 230, i = 1, 2, \ldots, 5.$$  

Then the volume of the modularized program is:

$$V_p^M = 5 \times 230 \log_2 40 = 6120$$

b) Complete modularization $C$:

In a complete modularization $C$ of $p$ of 5 equally sized modules we would have:

$$V_p^C = 5 \times 208 \log_2 36 = 5377$$

Comparison of Effort: Let $E_p$, $E_p^M$, $E_p^C$ be the effort to write program $p$ in the unmodularized form, and according to modularizations $M$ and $C$ resp. Then the following table gives a relative comparison of these quantities under the two assumptions, that they are proportional to the volume or to the square of the volume.

<table>
<thead>
<tr>
<th></th>
<th>If effort proportional to volume</th>
<th>If effort proportional to square of volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>Improvement of $E_p^M$ over $E_p$</td>
<td>21.4 %</td>
<td>38.3 %</td>
</tr>
<tr>
<td>Improvement of $E_p^C$ over $E_p$</td>
<td>31.0 %</td>
<td>52.4 %</td>
</tr>
<tr>
<td>Degradation of $E_p^M$ from $E_p$</td>
<td>27.3 %</td>
<td>62.1 %</td>
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<tr>
<td>Degradation of $E_p^C$ from $E_p$</td>
<td>44.9 %</td>
<td>110.0 %</td>
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REFERENCES
