Acyclic complexity (draft)

Abstract. In this paper we propose a quadratic code complexity measure [jan19] from the perspective of testing with the conjecture of indipendent enclosed scopes, the measure enfolds elementary condition collocation, nested and repeated structures.

1 Introduction

A Progam consist of a sequences of instructions. The instructions can be categorized into syntax, logic and arithmetic determining the program control flow.

Software complexity is related with modularity, coupling and cohesion hence quality. 40% to 80% of software costs are traced on maintenance and approximatly 40% on fixing defects [SG11].

Analysing code complexity helps to identify risk, finds potential defects to test critical functionality in detail, increase quality, cohesion and decrease maintainance [RB11].

2 Existing measures

Cyclomatic complexity (CC) has been widely discussed by various authors. The most used metric has been formulated by Thomas J. McCabe in 1976 [McC76].

$$m = e - n + 2 \tag{1}$$

Where, e = the amount of edges. n = the amount of nodes.

CC is linear in it's nature and correlation with lines of code (LOC), which is why Graylin JAY et al. [al.09] are suggesting to implement LOC as complexity measure.

Mir Muhammd Suleman Sarwar et al. [MMSS13] are pointing out that it neither takes into account the difference between combined decisions, elementary conditions nor repeating structures. Their adaptation of CC includes loop iterations

$$V(G)* = V(G) + \prod_{i=1}^{n} P_i$$
$$P_i = U_i - L_i + 1$$

Where, P_i = No. of iterations of ith loop. U_i = upper bound of ith loop. L_i = lower bound of ith loop and $V(G)*$ = adjusted cyclomatic complexity for any control flow graph "G". The measure combines control flow and statements exercised.

Brian A. Nejmeh. NPATH [Nej88] TODO.

Tevfik et al. [LB15] are providing a reasonable complutable measure: asymptotic path complexity covering nested structures and loops in comparison with CC and NPATH. TODO

2.1 Coverage

Test coverage metrics are providing quantitative representation of tested structures. The approach is to maximize coverage while minimizing testing effort. Each condition branches the flow into two control sub-paths, and determines the progression of the programm. The path of an isolated decision d_j thereby is given due to decisions and conditions (MC/DC) [RB11]. Let's define a condition c_j and it's path $\gamma : C \times \Sigma \to C^*$

$$\Sigma = \{true, false\}$$

$$C = \{c_0, c_1, c_2, c_3, ..., c_n\}, c_i \mapsto \Sigma$$

$$\varepsilon : C \to \Sigma \times C$$

$$D \subseteq \{C^*, S, E\}; d_i \in D$$

The transition function $alpha$

$$\alpha : D \times \Sigma^* \to \Sigma \times D$$

and the transition $\vdash$

$$\vdash \subseteq (\Sigma^* \times D \times \Sigma) \times (\Sigma^* \times D \times \Sigma)$$

The possible combinations of conditions on γ are arising through c_j's preceeding and succeeding condition flow. An acyclic transition path through c_j is described due to passing each condition once

$$\begin{aligned} P_j &= (v_i, d_i, b_i), ... \vdash (v_j, d_j, b_j) \vdash^* (v_n, d_n, b_n) \\ &= (c_i, b_i), ... \vdash (c_j, b_j) \vdash^* (c_n, b_n) \end{aligned}$$

where

$$\alpha(d_n, v_n) \mapsto E$$

with the mantle

$$P = (b_i, v_i, d_i) \vdash^* (b_n, v_n, d_n)$$

3 Acyclic complexity

Instead of combining arithmetic and logic we propose a metric [jan19] reflecting the logical test effort indicated by the amount of paths. The concept of basic paths described by [McC76] neglects loops and nesting. 100% sub-path combination coverage q is intricate due to exponential effort. Conditions are providing the logical structure of programs (Listing 1-12). Loops and recursions are construed due to their invariant and boundary [RB11], which is why their quantitative iteration increases inclination not path length. Let's define the inductive start of independent

$$\begin{aligned}\alpha_i =&(c_0, true) \to (c_1), (c_0, false) \to (c_1),\\ &(c_1, true) \to (E), (c_1, false) \to (E)\end{aligned}$$

and dependent structures

$$\begin{aligned}\alpha_d =&(c_0, true) \to (E), (c_0, false) \to (c_1),\\ &(c_1, true) \to (E), (c_1, false) \to (E)\end{aligned}$$

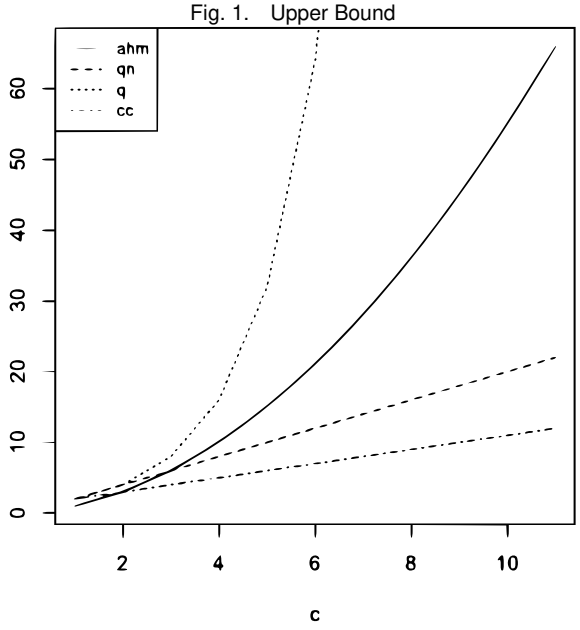
The isolated condition paths are delineate $log(2^n)$ subset of all q transition combinations from beginning to end. If we draw the spanning trees the first structure consists of four paths, where the second consists of three complete isolated paths.

The nesting of loops and conditions doesn't increase testing effort from the perspective of parameter combinations, the amount of paths yet decreases reciprocal with nesting. The perceived complexity of dependent structures increases contrary due to remembering previous preceeding conditions (Table 2).

Table 1. Condition collocation bound

$\|C\|$	loc		q		q_2		cc	ahm	
	min	max	min	max	min	max		max	min
1	1	l_0	2	2	2	2	2	1	$\frac{1}{2}$
2	1	l_1	3	4	3	4	3	3	1
3	1	l_2	4	8	4	6	4	6	$\frac{3}{2}$
4	1	l_3	5	16	5	8	5	10	2
5	1	l_4	6	32	6	10	6	15	$2\frac{1}{2}$
6	1	l_5	7	64	7	12	7	21	3
7	1	l_6	8	128	8	14	8	28	$3\frac{1}{2}$
...									
9	1	l_7	10	512	10	18	10	45	$4\frac{1}{4}$
...									
19	1	l_8	20	524288	20	38	20	190	$9\frac{1}{2}$
...									
49	1	l_9	50	$\sim 5 * 10^{14}$	50	98	50	1225	$24\frac{1}{2}$

Fig. 1. Upper Bound



Listing 1. plain singular

```
if (-1<1) { }
```

Listing 2. orthogonal dual

```
if (3>1 && 0<k) { }
```

Listing 3. tertiary orthogonal

```
if (2>1 && 7>k && 10>n) { }
```

Listing 4. orthogonal dual

```
if (2>1 || 0<k) { }
```

Listing 5. orthogonal dual nested

```
if (0<1) {
    ...
    if (2>k) { }
    ...
}
```

Listing 6. tertiary orthogonal nested

```
if (0<1 && 4>k) {
  ...
  if (11>n) { }
  ...
}
```

Listing 7. tertiary

```
if (2>1 && 0<k || 4>n) { }
```

Listing 8. parallel

```
if (2>1) { }
...
if (8>k) { }
```

Listing 9. tertiary parallel identical scope

```
if (2>1 || 0<k || 4>n) { }
```

Listing 10. tertiary orthogonal nested

```
if (2>1) {
  ...
  if (8>k) {
    ...
    if (0<n) { }
    ...
  }
}
```

Table 2. Collocation complexity

Listing	$\|C\|$	loc	q	q_2	cc	ahm
1	1	1	2	1	2	1
2	2	1	3	3	3	$1\frac{1}{2}$
3	3	1	4	5	4	$1\frac{5}{6}$
4	2	1	3	3	3	2
5	2	5	3	3	3	2
6	3	5	4	5	4	$2\frac{1}{2}$
7	3	1	4	5	4	$2\frac{1}{2}$
8	2	3	4	2	3	3
9	3	1	4	5	4	3
10	3	8	4	5	4	3
11	3	7	5	4	4	4
12	3	6	6	4	4	4
13	3	5	8	3	4	6

Listing 11. singular nested parallel

```
if (0<1) {
  ...
  if (4>k) { }
  ...
  if (8>n) { }
  ...
}
```

Listing 12. orthogonal singular parallel

```
if (0<1) {
  ...
  if (8>k) { }
  ...
}
if (0<n) { }
```

Listing 13. tertiary parallel different scope

```
if (-4<1) { }
...
if (4<k) { }
...
if (8>n) { }
```

Table 3. α_i flow matrix, $q_2(\alpha_i) = 2$

	s	c_0	c_1	e
s		t		
c_0			(t,f)	
c_1				(t,f)
e				

Table 4. α_d flow matrix, $q_2(\alpha_d) = 3$

	s	c_0	c_1	e
s		t		
c_0			f	t
c_1				(t,f)
e				

The exponential amount of condition combinations 2^n is disected due to exclusiv control flow q.

$$\begin{aligned} n &= |C| \\ 2^n &<= q <= n+1 \end{aligned} \tag{2}$$

. When every condition is isolated the amount of condensed edges (enclosed scope paths) q_2 in the condition flow matrix represents an intuitive measure indicating the condition flow (Table 2, 1, 3, 4).

The lower and upper bounds of possible isolated condensed condition transition paths are

$$\begin{aligned} 2*n >= q_2 >= n+1 \\ C_e \subset C; \quad m_u = |C| + |C_e| \end{aligned} \tag{3}$$

with $C_e \subset C$ nested conditions. The metric m_u is undifferentiated regarding condition nesting level. The subjective perception of increased complexity due to nesting and scope combination isn't taken care of, which is why we define the condition nesting function $\lambda(c_i)$

$$\begin{aligned} \frac{n}{2} < m_{ah} <= \frac{n(n+1)}{2} \\ m_{ah} = \quad \sum \lambda(c_i) \quad = \quad \sum_{i=0}^{n} \frac{r_i}{e_i} \end{aligned} \tag{4}$$

Fig. 2. Apache Tomcat 9.0.13

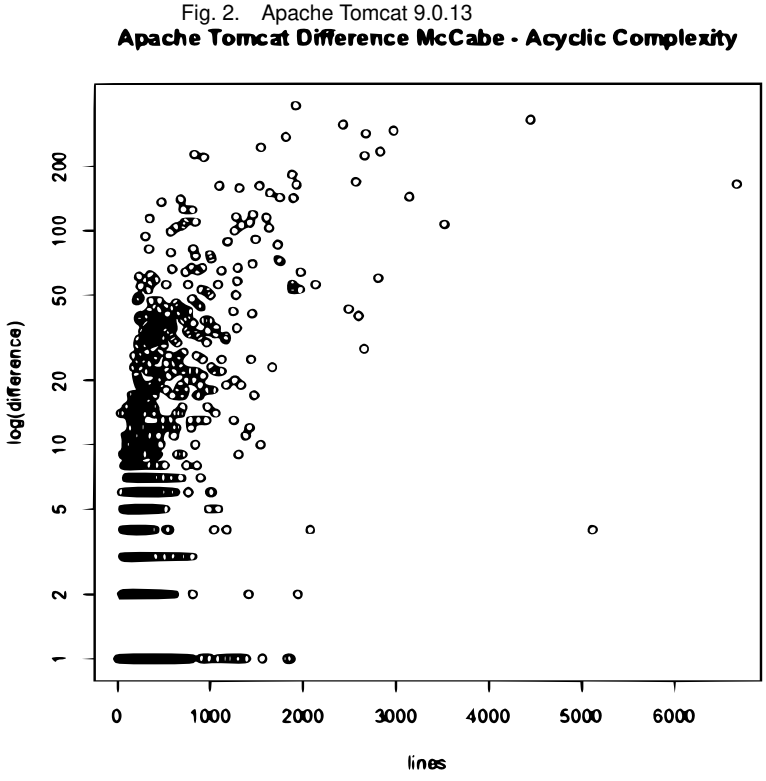
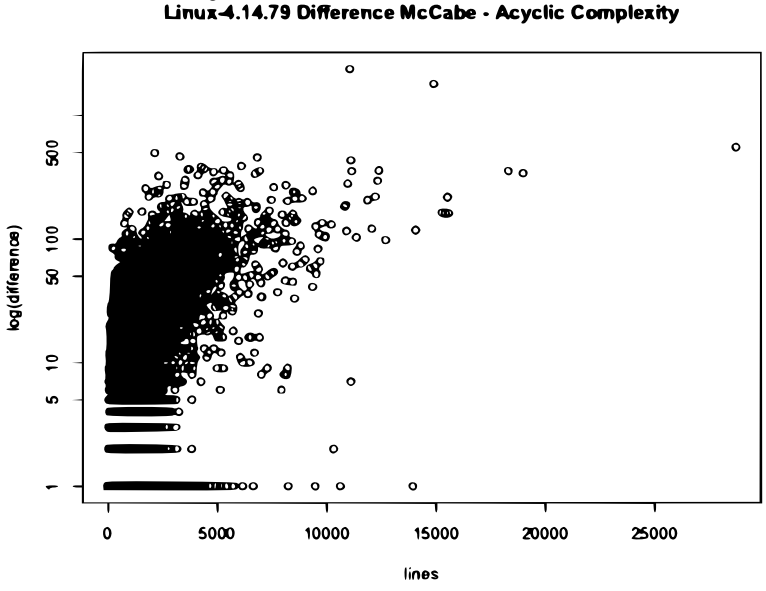


Fig. 3. Linux Kernel 4.14.79



The correlation of measure difference per line of code of two sampled open source projects appears logarithmic asymptotic Fig. (2), (3).

Table 5. Complexity Risk [Cha05]

ahm	risk
1-21	basic program
22-45	intricate, moderate risk
45-	circuitous, high risk

4 Conclusion

The suggested acyclic quadratic complexity measure (4) expresses the logical test effort of condensed path coverage, diminishing unapparent complex patterns quantifying control flow into reasonable absolute values.

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