Analysis of Software Design Principles under Complex Network Theory

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1 Introduction

One of the most well known Software Design principles in **Software Engineering** is High Cohesion (High Cohesion) and Low Coupling (Low Coupling), which is well described here [You79].

As this two principles states a *robust Software* should be design with Low Coupling between their modules and High Cohesion inside it.

In other words, a Software that fullfil this characteristics should be very connected in their minimum Functional Units (FU) (Functions inside same file, Methods inside a class, etc), and with few connections between their coarse grained FU (a.k.a Modules or Packages).

In this work, we are going to formulate some hypothesis which we believe it can been empirically proved and shown the relationship between these principles and how to measure with **Complex Network Theory (Complex Network Theory)**. At the same time, we are going to analysis different kinds of software of different sizes and build under different language paradigms to see if the tool set that Complex Network Theory provides are suitable for the general case.

2 Preliminaries

In this section we are going to describe how and why the different Language Paradigms are selected and what is the criterion for selection of different Software solutions to be evaluated.

On the other hand as well, we are going to formulate some hypothesis that are going to guide our work to see if our assumptions can empirically been proved using Complex Network Theory.

2.1 Context

We have selected the most important 2 main Language Paradigm to conduct the analysis: Functional Programming (Functional Programming) and Object Oriented Programming (Object Oriented Programming).

The reasons behind this decision are basically the following:

- **95%** of Software in the Industry are built with one of these 2 Paradigms according to the last results of this well-known survey [Inc20].
- Due to the intrinsic nature of each of those Paradigms we have some hypothesis that we are going to describe later that can lead to different conclusion and Metrics
- If we can deduce some Software Design properties analyzing these 2 Paradigms we can generalize for the rest because they are quite different in nature and covers almost the whole Industry.
- We also believe that Software Principles should apply indistinguishably the Paradigm.

On the other hand the selection of the programs to be analyzed are the following:

- Most of the software are Open Source or Free software that can be download publicly either from [Inc21] or from [Cen21].
- Software that are marked as **PRIVATE** are Big Projects from Privates Companies that don't want to reveal the Sources Code and Names for Commercial reasons.
- In the case of **PRIVATE** Functional Programming Solution, it belongs to a Company one of the authors of the current work is working right now.
- In the case of **PRIVATE** Object Oriented Programming Solution, it belongs to a Company one of the authors of the current work worked in the past.
- In both cases, taken anonymous data for conducting this analysis has been agreed with legal representatives of those Companies.

On the last hand we are going to use *Haskell* Programs for analyzing Functional Programming and *Java* Programs for Object Oriented Programming. We believe that right now both are the most representative ones in their Paradigm fields.

2.2 Hypothesis

In this work we are trying to prove the following **Hypothesis** that we consider can be proved using Complex Network Theory (Complex Network The-

ory).

Hypothesis 1. *Given any Software Program Solution, its Network Metrics should be between the 1st Quartile and 3rd Quartile, according to the average of the Network Metrics that we have been identified in this work, to be considered as a well Software Designed Solution.*

Hypothesis 2. *Any Object Oriented Programming Program have a better modularity in terms of Complex Network Theory Metric rather than Functional Programming Programs.*

Hypothesis 3. *The more Lines of Code (LoC) a Program have, the better Modularity it presents.*

Hypothesis 4. *If the Software follows the principle design of High Cohesion and Low Coupling, the Degree Distribution (Degree Distribution) of the Generated Graph should follow a power-law like.*

3 Results

In this section first we are going to describe the **Experiments** conducted and after that we have obtained after running the different experiments; this is what we call **Metrics** subsection.

3.1 Experiments

In this section we are going to described how the experiment have been set up in order to prepare the graphs for taking the desired metrics, that could allow us to explain and verify the proposed hypothesis.

3.1.1 Preliminaries

In order to determine if a Software fullfil the 2 Software Design Principles that we want to analyze, High Cohesion and Low Coupling, we need to extract the Call Dependency Graph (CDG) from the programs that we want to analyze.

In CDG, **nodes** are Functional Units: *Functions* in the case of Functional Programming and *Methods* in the case of Object Oriented Programming. An **edge** is when from inside a FU another FU is called or invoked.

Therefore, we need to build this Call Dependency Graph in order to establish how the different Modules are interconnected in order to measure Low Coupling and High Cohesion.

3.1.2 Building Graphs from Programs

In order to achieve the desired Call Dependency Graph we are going to use some specific tooling for each Paradigm. The following has been used on each case:

- **Functional Programming**: *function-call-graph* [dus19] is a Program that given a *Haskell* Source Code it outputs a *DOT* file with the Call Dependency Graph
- **Object Oriented Programming**: *java-callgraph* [gou18] is a Program that given a *Java* Compiled Jar it outputs a in *stdout* the Call Dependency Graph. In order to use only *DOT* files we have converted this output into *DOT* using a script that is under `code/script_java.sh`

All the resulting graphs are under their respective folders as you can see here A.

3.1.3 R Scripts

3.2 Metrics

3.2.1 FP Programs

Table 1: FP Programs Metrics 1

Program	N	E	K	Delta	MGD	Diameter
aeson	373	1167	6.26	0.0168	3.2450	9
amazonka	739	2366	6.40	0.0087	3.3202	8
async	60	120	4.00	0.0678	2.2458	6
attoparsec	61	180	5.90	0.0984	2.3978	5
beam	852	2215	5.20	0.0061	4.4898	11
cabal	2294	9115	7.95	0.0035	3.6017	10
co-log	97	159	3.28	0.0341	3.8937	9
conduit	457	875	3.83	0.0084	3.4084	9
containers	61	125	4.10	0.0683	3.3486	8
criterion	71	143	4.03	0.0575	3.3851	6
cryptol	1803	6540	7.25	0.0040	3.4149	9
cryptonite	292	652	4.47	0.0153	3.9468	9
dhall	707	2100	5.94	0.0084	3.6749	10
free	148	328	4.43	0.0302	5.0257	11
haskoin	569	1252	4.40	0.0077	5.0333	12
hedgehog	567	1383	4.88	0.0086	4.0136	12
helm	66	97	2.94	0.0452	3.4014	6

Table 1: FP Programs Metrics 1

Program	N	E	K	Delta	MGD	Diameter
hlint	266	624	4.69	0.0177	3.1839	10
lens	1118	3908	6.99	0.0063	2.7743	7
liquid	2568	7742	6.03	0.0023	3.3709	12
megaparsec	107	191	3.57	0.0337	4.4812	9
mios	169	397	4.70	0.0280	3.8088	10
optparse	174	464	5.33	0.0308	3.0912	7
pandoc	3640	15951	8.76	0.0024	3.3057	9
pipes	100	250	5.00	0.0505	2.2760	3
postgresql	501	1198	4.78	0.0096	3.8283	8
protolude	106	193	3.64	0.0347	4.0385	9
QuickCheck	264	699	5.30	0.0201	3.1726	8
reflex	222	425	3.83	0.0173	3.4672	12
relude	209	267	2.56	0.0123	6.0423	13
servant	237	445	3.76	0.0159	4.5035	11
snap	220	481	4.37	0.0200	3.8888	10
stm	70	171	4.89	0.0708	2.4576	5
summoner	194	458	4.72	0.0245	4.1549	10
text	105	170	3.24	0.0311	2.1471	4
vector	399	2953 1	4.80	0.0372	2.2036	6
yesod	367	748	4.08	0.0111	3.9486	12
PRIVATE	1088	2239	4.12	0.0038	4.7322	13

Table 2: FP Programs Metrics 2

Program	Modularity	Communities	Mean CC Coef	Mean LC Coef
aeson	0.4826	14	0.3521	0.3367
amazonka	0.4875	36	0.3273	0.2297
async	0.3403	9	0.4868	0.4141
attoparsec	0.2458	16	0.4757	0.2906
beam	0.6363	37	0.2488	0.2455
cabal	0.4939	96	0.2981	0.1915
co-log	0.6203	11	0.3144	0.4594
conduit	0.4621	35	0.3211	0.3221
containers	0.4138	5	0.3692	0.3520
criterion	0.6054	6	0.3516	0.3147
cryptol	0.5320	79	0.3169	0.2060
cryptonite	0.5825	25	0.2886	0.2790
dhall	0.5832	29	0.2975	0.2485

Table 2: FP Programs Metrics 2

Program	Modularity	Communities	Mean CC Coef	Mean LC Coef
free	0.5749	15	0.2570	0.4042
haskoin	0.7069	24	0.2270	0.2604
hedgehog	0.5792	44	0.2500	0.2757
helm	0.5655	4	0.3585	0.4360
hlint	0.4633	40	0.3589	0.3124
lens	0.4207	24	0.3884	0.4447
liquid	0.3388	19	0.3229	0.2057
megaparsec	0.6245	6	0.2847	0.2359
mios	0.5310	16	0.3081	0.2211
optparse	0.4466	8	0.3665	0.2248
pandoc	0.4614	22	0.3248	0.2379
pipes	0.3251	6	0.4704	0.6419
postgresql	0.6063	16	0.3060	0.5070
protolude	0.5651	8	0.3174	0.3897
QuickCheck	0.4640	19	0.3605	0.3677
reflex	0.5238	22	0.3469	0.4267
relude	0.7759	14	0.2051	0.3334
servant	0.6871	20	0.2463	0.3390
snap	0.5939	19	0.2894	0.2925
stm	0.3033	9	0.4538	0.3540
summoner	0.5757	17	0.2866	0.1518
text	0.3191	17	0.4863	0.5178
vector	0.1458	17	0.4825	0.4041
yesod	0.5858	13	0.2932	0.2731
PRIVATE	0.6461	63	0.2323	0.1480

3.2.2 FP Programs - Summary

Table 3: FP Programs - Summary Metrics 1

Type	N	E	K	Delta	MGD	Diameter
Min.	18.0	18	2.000	0.00230	2.147	3.000
1st Qu.	105.5	192	3.915	0.00850	3.214	7.500
Median	237.0	481	4.690	0.01770	3.419	9.000
Mean	547.7	1764	5.036	0.02786	3.593	8.872
3rd Qu.	568.0	1742	5.615	0.03440	3.981	10.500
Max.	3640.0	15951	14.800	0.11760	6.042	13.000

Table 4: FP Programs - Summary Metrics 2

Type	Modularity	Communities	Mean CC Coef	Mean LC Coef
Min.	0.1458	4.00	0.2051	0.1480
1st Qu.	0.4540	10.00	0.2876	0.2369
Median	0.5320	17.00	0.3174	0.3124
Mean	0.5097	38.08	0.3315	0.3201
3rd Qu.	0.5898	32.00	0.3597	0.3969
Max.	0.7759	419.00	0.4868	0.6419

3.2.3 OOP Programs

Table 5: OOP Programs Metrics 1

Program	N	E	K	Delta	MGD	Diameter
akka	291	290	1.99	0.0069	5.0948	12
commons-cli-1.4	133	178	2.68	0.0203	4.9707	13
commons-codec-1.10	443	599	2.70	0.0061	6.0180	16
commons-csv-1.8	168	177	2.11	0.0126	2.8243	8
commons-email-1.4	182	202	2.22	0.0123	4.7634	14
disruptor-3.4.2	457	632	2.77	0.0061	6.4273	16
ftpserver-core-1.0.6	1280	2319	3.62	0.0028	5.9379	17
grpc-core-1.34.1	3717	6544	3.52	0.0009	7.3362	24
guava	11786	18082	3.07	0.0003	7.4965	28
hbase-client-2.4.0	1724	1661	1.93	0.0011	8.4558	20
hsqldb-2.4.1	10394	22726	4.37	0.0004	6.6143	29
jackson-databind-2.12.0	1637	2718	3.32	0.0020	6.9562	25
javax.servlet-api-4.0.1	440	387	1.76	0.0040	7.8849	19
jedis-3.4.1	4413	6625	3.00	0.0007	7.1696	25
jersey-core-1.19.4	1409	2046	2.90	0.0021	6.4969	19
jetty-7.0.0.pre5	1881	2947	3.13	0.0017	6.7668	24
joda-time-2.10.6	3901	8201	4.20	0.0011	6.3395	22
jsch-0.1.54	1314	2296	3.49	0.0027	5.5298	16
jsoup-1.13.1	1623	3558	4.38	0.0027	6.2448	17
junit-4.13.1	1602	2186	2.73	0.0017	7.0309	20
mail-1.4.7	1068	1474	2.76	0.0026	9.4969	29
mariadb-java-client-2.7.1	2319	3678	3.17	0.0014	8.3089	24
mongo-java-driver-3.12.7	9147	16481	3.60	0.0004	6.8356	27
mx4j-3.0.2	887	1192	2.69	0.0030	6.4340	18
org.eclipse.jgit	12059	23175	3.84	0.0003	6.3935	22
pdfbox-2.0.22	8372	16353	3.91	0.0005	6.0460	28

Table 5: OOP Programs Metrics 1

Program	N	E	K	Delta	MGD	Diameter
poi-4.1.2	15971	26910	3.37	0.0002	7.5505	28
postgresql-42.2.18	3164	4740	3.00	0.0009	6.8974	20
resteasy-jaxrs-3.14.0.Final	4289	6818	3.18	0.0007	6.2748	18
runtime-3.10.0-v20140318-2214	441	547	2.48	0.0056	5.2854	13
slf4j-api-1.7.30	180	182	2.02	0.0113	4.8468	11
spring-security-core-5.4.2	1501	2314	3.08	0.0021	6.5614	22
spring-web-5.3.2	7219	11261	3.12	0.0004	7.5364	34
tomcat-embed-core-10.0.0	5386	8158	3.03	0.0006	7.3081	26
zookeeper-3.6.2	5284	9651	3.65	0.0007	6.3153	20
PRIVATE	339	529	3.12	0.0092	5.4404	13

Table 6: OOP Programs Metrics 2

Program	Modularity	Communities	Mean CC Coef	Mean LC Coef
akka	0.8347	39	0.0748	0
commons-cli-1.4	0.6542	20	0.1658	0
commons-codec-1.10	0.7835	67	0.0805	0
commons-csv-1.8	0.8219	29	0.0425	0
commons-email-1.4	0.7564	30	0.0893	0
disruptor-3.4.2	0.6508	99	0.1152	0
ftpserver-core-1.0.6	0.6670	213	0.1232	0
grpc-core-1.34.1	0.6385	779	0.1039	0
guava	0.7583	2025	0.0754	0
hbase-client-2.4.0	0.9013	419	0.0264	0
hsqldb-2.4.1	0.6779	1254	0.1260	0
jackson-databind-2.12.0	0.7138	228	0.1261	0
javax.servlet-api-4.0.1	0.8836	111	0.0348	0
jedis-3.4.1	0.7270	586	0.1225	0
jersey-core-1.19.4	0.8157	191	0.0776	0
jetty-7.0.0.pre5	0.7034	286	0.1097	0
joda-time-2.10.6	0.7110	461	0.1260	0
jsch-0.1.54	0.6709	203	0.1223	0
jsoup-1.13.1	0.7439	204	0.1290	0
junit-4.13.1	0.7672	254	0.0888	0
mail-1.4.7	0.7154	195	0.0872	0
mariadb-java-client-2.7.1	0.7519	244	0.0965	0
mongo-java-driver-3.12.7	0.6193	1731	0.1066	0
mx4j-3.0.2	0.7091	106	0.1061	0

Table 6: OOP Programs Metrics 2

Program	Modularity	Communities	Mean CC Coef	Mean LC Coef
org.eclipse.jgit	0.6403	1404	0.1293	0
pdfbox-2.0.22	0.6890	863	0.1311	0
poi-4.1.2	0.7582	2181	0.0958	0
postgresql-42.2.18	0.7695	506	0.0790	0
resteasy-jaxrs-3.14.0.Final	0.6456	888	0.0898	0
runtime-3.10.0-v20140318-2214	0.7279	62	0.1229	0
slf4j-api-1.7.30	0.8531	32	0.0670	0
spring-security-core-5.4.2	0.6879	216	0.1068	0
spring-web-5.3.2	0.6956	1315	0.0871	0
tomcat-embed-core-10.0.0	0.7786	684	0.0907	0
zookeeper-3.6.2	0.6624	962	0.1052	0
PRIVATE	0.6676	40	0.1739	0

3.2.4 OOP Programs - Summary

Table 7: OOP Programs - Summary Metrics 1

Type	N	E	K	Delta	MGD	Diameter
Min.	133	177	1.760	0.000200	2.824	8.00
1st Qu.	672	912	2.715	0.000700	6.032	16.50
Median	1637	2718	3.120	0.001700	6.434	20.00
Mean	3456	5984	3.094	0.003403	6.489	20.46
3rd Qu.	4351	8149	3.505	0.003500	7.100	24.50
Max.	15971	26910	4.380	0.020300	9.497	34.00

Table 8: OOP Programs - Summary Metrics 2

Type	Modularity	Communities	Mean CC Coef	Mean LC Coef
Min.	0.6193	20.0	0.02640	0
1st Qu.	0.6693	108.5	0.08715	0
Median	0.7110	244.0	0.10610	0
Mean	0.7256	512.0	0.10227	0
3rd Qu.	0.7628	731.5	0.12305	0
Max.	0.9013	2181.0	0.17390	0

4 Discussion and Analysis

5 Conclusions

References

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A Organization

- **code**: Under this folder you are going to find *R Scripts* code for conducting this analysis.
- **fp_graphs**: *DOT* files that contains the Dependency Graph Representation of each Functional Programming Program
- **oop_graphs**: *DOT* files that contains the Dependency Graph Representation of each Object Oriented Programming Program
- **report**: This report in Latex and PDF format.

B Programs Details - Line of Codes

B.1 FP Programs

Table 9: FP Analyzed Programs

Program	LoC
aeson	6948

Table 9: FP Analyzed Programs

Program	LoC
amazonka	715531
async	743
attoparsec	4718
beam	20151
cabal	102525
co-log	1436
conduit	12963
containers	19556
criterion	2421
cryptol	30740
cryptonite	18763
dhall	29058
free	4472
fused-effects	4145
ghcid	1664
haskoin	12066
hedgehog	8277
helm	2071
hlint	6306
lens	16691
liquid	133740
megaparsec	8144
mios	6178
mtl	932
optparse	3220
pandoc	69179
pipes	1969
postgresql	6596
protolude	1901
quickcheck	5077
reflex	10062
relude	2913
servant	15725
snap	5310
stm	1550
summoner	4025
text	9783
vector	12166

Table 9: FP Analyzed Programs

Program	LoC
yesod	19971
PRIVATE PROGRAM	26975

B.2 OOP Analytzed Programs

Table 10: OOP Analyzed Programs

Program	LoC
akka-actor_2.10-2.3.9	35702
commons-cli-1.4	830
commons-codec-1.10	2231
commons-csv-1.8	607
commons-email-1.4	760
disruptor-3.4.2	1131
ftpserver-core-1.0.6	4052
grpc-core-1.34.1	9142
guava-28.1-jre	37216
hbase-client-2.4.0	33209
hsqldb-2.4.1	30578
jackson-databind-2.12.0	22516
javax.servlet-api-4.0.1	901
jedis-3.4.1	12640
jersey-core-1.19.4	5656
jetty-7.0.0.pre5	6727
joda-time-2.10.6	8891
jsch-0.1.54	4833
jsoup-1.13.1	5955
junit-4.13.1	5803
mail-1.4.7	8817
mariadb-java-client-2.7.1	9229
mongo-java-driver-3.12.7	35676
mx4j-3.0.2	6902
org.eclipse.jgit	42417
pdfbox-2.0.22	26413
poi-4.1.2	44691
postgresql-42.2.18	15199
resteasy-jaxrs-3.14.0.Final	15267
runtime-3.10.0-v20140318-2214	921

Table 10: OOP Analyzed Programs

Program	LoC
slf4j-api-1.7.30	763
spring-security-core-5.4.2	4726
spring-web-5.3.2	21393
tomcat-embed-core-10.0.0	47185
zookeeper-3.6.2	19207
PRIVATE PROGRAM	2143