# Reviewing the Health of Software Ecosystems – A Conceptual Framework Proposal

Konstantinos Manikas and Klaus Marius Hansen

Department of Computer Science (DIKU)
University of Copenhagen
Njalsgade 128
2300 Copenhagen S
Denmark
{kmanikas,klausmh}@diku.dk

**Abstract.** The health of a software ecosystem is an indication of how well the ecosystem is functioning. The measurement of health can point to issues that need to be addressed in the ecosystem and areas for the ecosystem to improve. However, the software ecosystem field lacks an applicable way to measure and evaluate health. In this work, we review the literature related to the concept of software ecosystem health and the literature that inspired the software ecosystem health literature (a total of 23 papers) and (i) identify that the main source of inspiration is the health of business ecosystems while also influenced by theories from natural ecosystems and open source, (ii) identify two areas where software ecosystems differ from business and natural ecosystems, and (iii) propose a conceptual framework for defining and measuring the health of software ecosystems.

**Key words:** software ecosystems, ecosystem health, software ecosystem health framework, software ecosystem health measurement

## 1 Introduction

The notion of software ecosystems (SECOs) is gaining popularity as a means of expanding development, better positioning in the market, or increasing revenues. There is a number of definitions of SECOs in the literature [1, 2, 3, 4]. In this work we define a software ecosystem as *"the interaction of a set of actors on top of a common technological platform that results in a number of software solutions or services. Each actor is motivated by a set of interests or business models and connected to the rest of the actors and the ecosystem as a whole with symbiotic relationships, while, the technological platform is structured in a way that allows the involvement and contribution of the different actors"* [5]. Today, software ecosystems come with a wide variability of characteristics: platform structure, actor participation, ecosystem orchestration, and revenue models, to name a few. This makes the establishment of methods for measuring and evaluating the activity of the ecosystem challenging. The SECO literature refers to the concept of "health" of an ecosystem as a way to monitor ecosystem activity, identify and predict areas for improvement, and evaluate changes in the ecosystem. However, the measurement of the SECO health is not yet fully achieved.

We tentatively define the health of a software ecosystem as the ability of the ecosystem to endure and remain variable and productive over time. In this work, we aim to get closer to SECO health measurement by reviewing the literature that is elaborating on SECO health. In doing so, we identify that the SECO health literature is borrowing definitions and measurement of health from other fields and expand our literature review focus to include additional ecosystem health fields (explained in section 2). We review the wider ecosystem health literature body and report the health definitions and measurements (section 3). We identify two main differences between SECOs and business and natural ecosystems and, based on previous work, we propose a conceptual framework for defining and measuring the health of SECOs (section 4). Finally, in section 5 we discuss threats to validity and future work and conclude in section 6.

## 2 Defining the Health Literature Body

The method used for defining the literature body consisted of the following steps:

(i) Defining the SECO health literature. To define the literature related to the SECO health, we used as input the papers identified in our recent systematic literature review [5]. In [5], we identified a number of papers referring to the concept of ecosystem health. The papers have a wide variability on the level of detail they provide on the ecosystem health ranging from mere reference to the concept (e.g., [6, 7, 8]) to papers in which health forms part of the main focus (e.g., [9, 10]).

(ii) Defining wider ecosystem health literature. While examining the SECO health literature, we noticed that the definition and analysis of health is borrowed from other types of ecosystems not covered by the SECO health literature . Using the "snowballing technique" [11], we followed the references of the SECO health literature and evaluated whether these are related to the health of an ecosystem [1]. The criteria for accepting a paper in the literature was that it would (a) define the health or sustainability of an ecosystem or (b) elaborate on ways of measuring health.

Table 1 shows the literature body and the papers that are referenced by each document. The SECO health literature that resulted from step (i) is the first row while the literature from step (ii) are the remaining. We have organized the papers into categories according to their field: software ecosystems (SECOs), business ecosystems (BECOs)[2], natural ecosystems, and open source software (OSS). The main purpose of listing the categories is to show the fields that

[1] We also followed references of the selected references that appeared relevant, resulting in a number of papers ([12, 13])

[2] Paper [27] is defining the field of "IT ecosystems", though, as a BECO with IT products.

| Type | Paper | Source |
|---|---|---|
| SECO | [14, 10, 15, 9, 16, 17, 7, 18, 8, 19, 20, 21, 6] | Health literature from [5] |
| BECO | [22] | [14, 9, 21, 10, 15, 23, 24] |
| | [25] | [14, 7, 10, 16, 6, 23] |
| | [23] | [14, 10, 9, 16, 18] |
| | [26] | [18, 8, 23] |
| | [27] | [20] |
| | [24] | [9] |
| Natural ecosystems | [28] | [9] |
| | [12] | [28] |
| | [13] | [28] |
| OSS | [29] | [19] |
| **Total:** | 23 | |

**Table 1.** List of the documents in the health literature and the documents referring to them.

influenced SECO health. In this work, we have not looked at the health definition and measurement in the other fields outside the references of the SECO health literature and, thus, do not claim that these papers are representative of each field.

## 3 Ecosystem Health

Following the separation of ecosystem fields in Table 1, we list and discuss the papers per ecosystem that have influenced the SECO health literature.

### 3.1 Natural Ecosystems

The field of (natural) ecosystems inspired the rest of the ecosystem fields examined here (BECO and SECO) and it is the field where the concept of ecosystem health was initially formulated. Costanza [12], defines a healthy ecosystem as "being 'stable and sustainable'; maintaining its organization and autonomy over time and its resilience to stress". In addition, Rapport et al. [28], referring to a collection of papers in the literature, define three indicators for health of an ecosystem: *Vigor* that indicates how active or productive an ecosystem is, *Organization* that indicates the variability of species, and *Resilience* that indicates the ability of the ecosystem to "maintain structure and function in the presence of stress". The characterization of an ecosystem in terms of structure and function is also discussed by Schaeffer et al. in [13]. They parallelize ecosystem health with human health and define it as the "absence of disease". They identify structure as "numbers of kinds of organisms, biomass etc." and function as "activity, production, decomposition etc.". These are seen as measures used to define the ecosystem health. Furthermore, Schaeffer et al., referring to the literature, list four ways that structure and function may be connected: (a) tightly connected, where neither can change without the change of the other, (b) structure changes does not affect function, (c) function changes do not affect structure, and, (d) structure and function appear unconnected.

### 3.2 Business Ecosystems

BECO health is the area that has inspired most of the SECO health literature. In the BECO literature, the concept of health is mainly defined as the ability of a BECO to provide "durably growing opportunities for its members and for those who depend on it" [26][3]. Iansiti and Levien [25, 26, 22] and Iansiti and Richards [27] define the health of a business ecosystem using three measures:

Productivity. Inspired by natural ecosystems' ability to create energy from input sources (e.g., sunlight or mineral nutrients), BECO productivity is the ability of an ecosystem to "convert raw materials of innovation into lowered costs and new products and functions" [26]. Productivity in BECOs can be measured by means of (a) total factor productivity, (b) productivity improvement over time, and (c) delivery of innovations, the ability of the ecosystem to adapt and deliver to its members new technologies, ideas, or process.

Robustness. The ability of the ecosystem to sustain shocks, perturbations, and disruptions. Robustness is measured in terms of (a) survival rates, the survival of actors over time, (b) persistence of ecosystem structure, the extent to which actor relationships are kept unchanged, (c) predictability, the extent to which even if shocks alter the relationships of actors, a main core of the ecosystem remains solid, (d) limited obsolescence, whether the ecosystem has a limited invested technology or components that becomes obsolete after a shock, and (e) continuity of use experience and use cases, the extent to which products gradually evolve in response to new technologies rather than changing abruptly.

Niche Creation or Innovation. The ability of the ecosystem to increase meaningful actor diversity over time. Niche creation is measured in terms of (i) growth in company variety and (ii) growth in product and technical variety (value creation) that measures the increase in value the growth brings.

Iansiti and Levien and Iansiti and Richards also propose three ecosystem actor roles, inspired by natural ecosystems, that affect the health of a BECO:

Keystone. Is an actor that normally occupies or creates highly connected hubs of actors and promotes the health of the ecosystem by providing value to

[3] Similar definitions appear in [22, 27]

the surrounding actors. Keystones promote the health of the ecosystem by increasing the variability, provide value to the connected actors and thus increase productivity, and increase robustness by protecting connected actors from external shocks.

Dominators. Are the actors that control the "value capture and value creation" [22] of the ecosystem. They tend to expand by taking over the functions of other actors thus eventually eliminating the actors. Dominators are harmful for the health of an ecosystem as they reduce diversity

Niche (players or firms). Usually form the main volume of the ecosystem actors drawing value from the keystones. A niche player aims to separate from the other niche players by developing special functions.

Typically, a keystone provides value to a number of actors that can be either niche players trying to develop or dominators trying to dominate the functions of the surrounding actors. The roles of the BECO actors are also examined by Iyer and Lee [24]. They classify the actors in an ecosystem in (a) hubs, (b) brokers that connect two sets of actors, and, (c) bridges that are essential for the connectedness of the ecosystem. A hub can demonstrate keystone, dominator, or niche player characteristics.

Hartigh et al. [23] use the work of Iansiti and Levien and Iansiti and Richards (referred to as "Iansiti" hereafter) to measure the health of the Dutch IT industry. They define BECO health using two long-term parameters: the financial well-being and strength of the network and break down the health in two components: partner health and network health. Partner health evaluates the health of each individual actor of the ecosystem. A healthy ecosystem is composed of productive actors contributing to the productivity of the ecosystem while unproductive actors will have difficulty surviving. The survival of the actors is analogous to the Iansiti robustness measure. Network health is measured in terms of actor connectivity. Highly connected actors contribute to the robustness of the ecosystem as the actors are not easily affected by external shocks. In addition, a healthy ecosystem contains clusters of different nature, thus increasing the possibility of niche creation.

### 3.3 OSS

Wahyudin et al. [29] study the concept of health in OSS projects. They define the health of an OSS project as "survivability", the ability of the project to survive throughout time. An OSS project is healthy and survives if the software produced by the project is used by a number of users and maintained by a number of developers. They identify three measures that affect the health of an open source project:

The developer community liveliness. The project should attract new developers and keep the existing by boosting their motivation. Wahyudin et al. break down an OSS developer's motivation in intellectual stimulation, skill enhancement, and access to source code and user needs.

The user community liveliness. The users of OSS software play an active role in the evolution of the project by reporting bugs and requesting new features. A large, active user community indicates that the software produced is usable and of good quality.

The product quality. A product that is competitive with commercial products in use and quality will attract users and developers, increase the activity in the project, and therefore enhance survivability.

### 3.4 Software Ecosystems

In the field of SECO, Berk et al. [9] propose SECO-SAM, a model for the assessment of a SECO strategy based on SECO health. In their model, they make an analogy between the health of an ecosystem and human health and propose that SECO health is influenced by the biology of the ecosystem, the lifestyle, the environment, and the intervention of healthcare organizations while they measure the SECO health adopting the Iansiti productivity, robustness, and niche creation (PRN) measures. Jansen et al. [10] elaborate on a three-level model of SECOs, published in [7], consisting of the organization scope level, SECO level, and software supply network level. They define SECO health as a characteristic of the software supply network level using the Iansiti PRN measures. Additionally, they propose the application of the Hartigh et al. [23] measures for defining the health at the SECO level. Angeren et al. [14] show that SECO robustness of the Iansiti PRN measures is an important factor for vendors that choose to depend on a SECO.

In OSS, McGregor [20] translates the Iansiti PRN measures to measures that can be applied to open source projects, while Kilamo et al. [18] propose a framework for going from a proprietary to a Free/Libre/Open Source Software (FLOSS) SECO. One of the framework activities is setting up a "community watchdog" that assesses the community, the software, and "how well the objectives of the company are met". The watchdog indirectly assesses the health while they provide a number of measures to be applied in FLOSS SECOs.

Looking at the SECO health literature, we note that the main source of inspiration is BECO health when trying to define and measure SECO health or health-related parameters (e.g., keystone-dominator strategies) with 11 out of the 13 papers referring to at least one of the Iansiti authored papers [22, 25, 26, 27]. Although the health of a BECO is very similar to the SECO health, we identify a number of differences between the two. In the next section, we explain the differences and build on top of the existing literature to define a framework for SECO health.

## 4 A SECO Health Proposal

When analyzing the health of SECOs, we identify that similarly to BECOs and natural ecosystems, the set of actors, their activity and the network they form is an indication of the level of prosperity and sustainability of the ecosystem. However, one main difference of SECOs from BECOs and natural ecosystems is in the nature of the products of the actors and, eventually, of the whole ecosystem. The BECO approach explained in the previous section is aligned with the natural ecosystem approach of actors and products, where the products of the ecosystem (i.e. energy) are represented by the actors (i.e., species) by enclosing energy in the energy flow between the species. In other words, a herbivorous species eats a plant and is eaten by a carnivorous species. This herbivorous species is both an actor and a product in the ecosystem and changes in the health of this species (e.g., number decrease) affects the energy enclosed (product) by this species and, thus, the carnivorous species.

In SECOs, the actors are differentiated from the products. The main product of the actors is software, either as a common software/technological platform, as software components, or services based on software components. The symbiosis of this software can influence the health of a SECO. The influence that the software components have on the SECO health is independent of the actor health. An example would be an actor that creates a software component that enhances the component interoperability and increases the use of the platform and thus contributing to the SECO health. At the same time, this actor might not have a successful revenue model for this software component and end up loosing a big part of the invested effort. The actor will have a negative influence on the SECO health because of low productivity and possibly robustness, while the software component will have a positive influence.

One additional difference of SECOs to BECO/natural ecosystems is that in SECOs there is an entity organizing and managing the ecosystem, the orchestrator. The orchestrator, whether a for-profit organization or an OSS community, is typically managing the ecosystem by running the platform and creating rules and processes for actors and software. The orchestration of the SECO thus has a significant effect on the health of the ecosystem.

The proposed SECO health framework can be seen in Figure 1. We depict three main components that affect the SECO health: (i) the actors, (ii) the software and (iii) the orchestration. In (i), we separate between the individual health of an actor and the health of the network of actors and similarly in (ii) between the individual component health, the ecosystem platform health and the software network health.

### 4.1 Individual Actor Health

The health of the individual actors influences the overall health of the ecosystem. The actor health can be measured in similar terms to a BECO actor. The actor's productivity and robustness influence the ecosystem. The active participation and engagement of actors brings value to the ecosystem, while the actor's robustness increases the probability that the actor exists and remains involved in the ecosystem activity in the future. If the SECO is a proprietary ecosystem or consists of for-profit organisations, the partner health measures of Hartigh et al. [23] can be directly applied. If in the OSS domain, the actor health can be

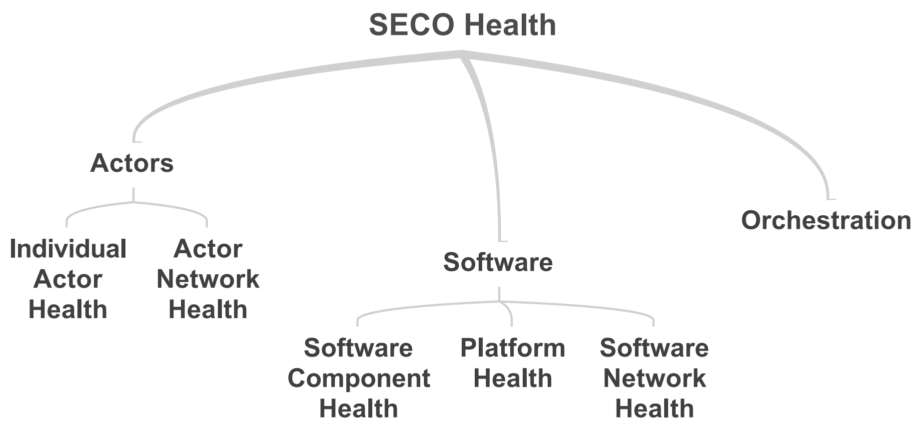


**Fig. 1.** The SECO health framework breakdown.

assessed in a way similar to Wahyudin et al [29]: measuring the actor activity in the ecosystem (commits, mailing list activity etc.). In that case, an indication of actor robustness is the active participation in the ecosystem over a long period of time. An actor being an active participant in the ecosystem for a long period of time has lower probability of dropping out of the ecosystem than an actor that recently started contributing to the ecosystem.

### 4.2 Actor Network Health

The network of actors and their interaction plays an important role in the SECO health. The PRN measurements are applicable here, so is the network health perspective of Hartigh et al. [23]. Additionally, the individual actor health may be weighted according to the role of the actor in the network. A keystone with low productivity or robustness will have greater effect in the ecosystem than a niche player with low productivity or robustness.

### 4.3 Software Component Health

The health of a software component can be measured in terms of, among others, (i) reliability, (ii) availability, (iii) modifiability and prevention of ripple effects, and (iv) interoperability, the ability to interact with, to the extent applicable, the platform and other components. In SECOs, the software components are, in most cases, also the *products* of the ecosystem. The health of such a software component is also influenced by the relative demand and product quality, e.g., how popular is the product and how it is performing in comparison to possible alternatives. This demand is also affected by whether the product is internal, i.e., products intended for use mainly by the ecosystem actors, e.g., the technological platform or external, i.e., products consumed externally to the ecosystem.

### 4.4 Platform Health

The health characterization of the software components above can be applied to the technological platform of a SECO, since it is a software component itself. However, the technological platform, might have an additional role: depending on how the SECO is organized and managed, the platform reflects possible orchestration actions (rules, processes, or management decisions). The measurement of the platform health should not reflect how the orchestration affects the SECO health (as this is reflected in the orchestration influence on SECO health seen below), but the effectiveness of applying the orchestration actions.

### 4.5 Software Network Health

The software components are connected and interacting with other components in the ecosystem forming the software network. Graph measures such as connectivity and clustering coefficient show to what extent the components interact [30]. Additionally, the categorization of the activity of hubs into keystone and dominator indicate the level of healthy interaction. Analogous to the Iansiti descriptions in the previous section, an example of keystone activity can be a component that provides interfaces to parts of its functionality for the neighboring components to consume, while in a dominator activity the component would intent to take over functionality of the neighboring components.

### 4.6 Orchestration Influence to Health

The orchestrator can monitor the health of the ecosystem and take measures to promote ecosystem health if necessary. This requires that the orchestrator has a good overview of the ecosystem and is consulting effective measurements (e.g., ecosystem health). Additionally, the orchestrator can act by creating/refining rules and processes for the actors, communicating plans to the actors (e.g., by road-mapping), organizing the ecosystem development through, e.g., release management, making changes to the platform and other software components, changing the revenue model for internal products, and controlling the actor population and motivation by modifying the model by which the actors participate in the ecosystem. The orchestration of a SECO, i.e., the actions of the orchestrator, possibly based on monitoring and evaluation, influences SECO health.

### 4.7 Other Influences on SECO Health

Additionally, there might also be influences on the SECO health that are external to the ecosystem. This kind of influences are referred to as "(external) perturbation" in the literature [28, 22, 26, 27] and are disturbances that are outside the control of the ecosystem actors. Influences of this kind might be the establishment or rise of a competitive ecosystem or a radical technological or legal change.

## 5 Threats to Validity and Future Work

The wider ecosystem health literature used in this study was identified through the references in the SECO health literature as our focus was literature that influenced the SECO health literature. As already mentioned, the literature on each field (apart from SECO) is not necessarily the representative or most influential work in the field. Identification of the most influential work and possible literature mapping of the health in each of the fields (BECO, natural ecosystem, OSS/FLOSS) might bring perspectives into the SECO health that have been overlooked. Additionally, we speculate that the influence of the difference fields to the SECO health is not necessary reflected in the number of papers appearing in this work. Natural ecosystem have had a greater impact on SECO health concepts, but most of it is indirect through the health of BECOs.

Moreover, the proposed conceptual framework, at this point, does not go into detail on the different kinds of actors. An expansion of the model would further analyze on the nature of the actors, e.g., developing companies, resellers, value-adding-resellers, and possibly include their influence on health. Additionally, although the model included products, it did not include customers or end-users. The influence of entities of this kind could be discussed in future work.

## 6 Conclusion

In this paper, we analyzed the concept of software ecosystem (SECO) health. In order to define SECO health and its measurement, we examined the SECO health literature, a literature body of 13 papers touching upon the concept of SECO health. We identified that the health research is mainly inspired by three fields: business ecosystems (BECO), natural ecosystems, and open source software, with BECO being the main source of inspiration in 11 out of the 13 SECO health papers. We reviewed the wider ecosystem health literature, consisting of 23 papers, explained how they define and measure the health of an ecosystem and concluded with two contributions: (i) We identify two differences between the SECO and business and natural ecosystems: (a) they perceive products in the ecosystem differently. BECOs and natural ecosystems perceive actors as a product per se, while in SECOs an actor produces software components or services. (b) SECOs have an orchestrator entity managing the ecosystem, something that does not appear in the BECO/natural ecosystem literature. (ii) We propose a logical framework for defining and measuring the SECO health consisting of the health of (a) each individual actor, (b) network of actors, (c) each individual software component, (d) platform, (e) software network, and (f) orchestrator. The purpose of this study is to create a discussion on the particularities of SECO health and bring the community closer to a measurable way of defining the health of software ecosystems.

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