

# Stigmergy within Web Modelling Languages: Positive Feedback Mechanisms

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**Abstract**— Stigmergy is a biological term originally used when discussing insect or swarm behaviour, and describes a model supporting environment-based communication separating artefacts from agents. This phenomenon is demonstrated in the behavior of ants and their food foraging supported by pheromone trails, or similarly termites and their termite nest building process. What is interesting with this mechanism is that highly organized societies are formed without an apparent central management function. We see design features in Web sites that mimic stigmergic mechanisms as part of the User Interface and we have created generalizations of these patterns. Software development and Web site development techniques have evolved significantly over the past 20 years. Recent progress in this area proposes languages to model web applications to facilitate the nuances specific to these developments. These modeling languages provide a suitable framework for building reusable components encapsulating our design patterns of stigmergy. We hypothesize that incorporating stigmergy as a separate feature of a site's primary function will ultimately lead to enhanced user coordination.

*Keywords*-web collaboration; virtual pheromones; stigmergy.

## I. INTRODUCTION

The World Wide Web has transitioned from its historically static content to a new, dynamic experience emerging through collaborative websites and social networking. We seek to understand a specific set of emerging designs that we believe are indicative of a natural phenomenon called stigmergy [1].

In biology, stigmergy describes a mechanism of indirect communication where the actions of individuals affect the behavior of others (and their own). This communication mechanism describes what has been considered as apparent cooperative behavior of insects' during various activities. An example of this is the food gathering activities of ants which exploit pheromone trails. To find the most recent and relevant food source the ants select paths to follow based on the strength of specific trails. The environment embedded pheromones is considered a form of indirect

communication. This stigmergic communication comprises of an explicit message in the pheromone to gather food, and an implicit signal through the current level of decay: information within the trails themselves show which trail will currently lead to a food source opposed to those leading to a depleted food source.

There are multiple varieties of stigmergy and our research to date has modeled and documented this [2, 3]. We have created generic design proto-patterns from observing stigmergy in numerous Web sites, however this paper will focus on those observed within Facebook. The User Interface (UI) designs observed provide representations of user feedback along with representations of behavior trends from unintentional interactions recorded as trace data. Examples of these UI designs can be seen in Facebook where users "Like" other user contributions causing an area of focused interest. Another example can be seen where Facebook has introduced a "Seen By" representation of feedback where the number of users navigating to an article is presented as a trail (or virtual footsteps).

Web Modeling Language (WebML)[4] is a method of modeling data content, user interaction and navigation flow for Web 2.0 applications. WebML provides a way to design the mapping of a data model to different UI views and the navigation paths between those views. The pertinent aspect of the WebML framework to our research question is that WebML is designed to be extensible to facilitate new concepts, interface types and event types. Our research uses WebML and the WebRatio development environment allowing stigmergy to be easily incorporated into a site as reusable components keeping the core code-base separate from the stigmergic features. Given the Web 2.0 UI designs that we have observed and a thorough analysis of how they correlate to stigmergy, we have implemented generic UI components as standard elements for web site development to exploit stigmergic communication.

Our research project focuses on creating a model of stigmergy that we can use to design feedback mechanisms into Web applications. From this model we can describe a

framework to exploit stigmergy in the collaborative environment provided by specific Web applications. This paper illustrates how we create design patterns in an Integrated Development Environment (IDE) to capture the features of stigmergy as a separate aspect to core Web site features. The research contribution of the PhD project is to determine the efficacy of incorporating stigmergy into site design; this paper makes a significant contribution by documenting our current progress capturing user input (positive feedback) using reusable stigmergic design patterns readily included into primary Web site functionality. Future work will involve testing our model of stigmergy using our design patterns in experiments with users to test how they react to the presence of stigmergic features in a Web 2.0 site when compared with a similar Web 2.0 site without the stigmergic features.

This paper will introduce our research question based on our hypothesis in Section II. Section III will provide a brief Literature Review describing previous work on Stigmergy providing key facets of our model development. Section IV will detail our research methodology and explain why we have chosen a multi-method approach. Section V will detail our current progress including an overview of our developed model of stigmergy, data model and interface components implementing the positive feedback mechanisms. Section VI will discuss problems yet to be solved and will be followed by the conclusion in Section VII.

## II. RESEARCH PROBLEM

Our hypothesis is that stigmergic behaviour is inherent in collaborative Web environments and that a framework to support all attributes and dynamics of stigmergy will facilitate higher quality collaborative outcomes. This leads to the question: Does the Web enable us to build better collaborative sites when the attributes and dynamics of stigmergy are fully exploited? Are there facets of stigmergy missing in the Web environment that could be used in capturing implicit communication otherwise lost? To answer this question the project has required a clear definition of stigmergy and how it manifests in Web environments. There is significant research into stigmergy, virtual pheromones and swarm intelligence re-creating stigmergic behaviour; but limited research into its relevance as a design pattern to coordinate human behaviour. If we can build a model identifying stigmergy in Web environments, we speculate we can create a methodology to build sites benefiting from this phenomenon.

## III. STATE OF THE ART

The word stigmergy “is formed from the Greek words stigma ‘sign’ and ergon ‘action’” [5] and is used within biology to describe the way non-rational, autonomous agents (such as termites or ants) collaborate to achieve complex tasks thereby displaying some type of emergent swarm-intelligence [6]. These agents use pheromones as

signs embedded within the environment to trigger behaviour or actions in other agents in the swarm.

Stigmergy was first introduced in 1959 by a French zoologist named Pierre-Paul Grasse [7] to describe how insects appear to coordinate successfully despite having no centralized management structure or direct observable intercommunication [1]. A simplified definition of stigmergy is: a process by which agents communicate indirectly between one and other through their environment. More specifically, the behaviour of agents is influenced or determined by the behaviour of agents which have interacted with the spatio-temporal environment previously [8]. Essentially stigmergy describes an autonomous system enabling self-organisation, self-optimisation and self-contextualisation in a light-weight and scalable mechanism [9]. This is interpreted as the associated mechanisms and emergent behaviour enabling the selection of the optimal solution without the prerequisite of knowing anything about the environment.

Stigmergy is a compelling phenomenon because it describes a positive feedback system where the signal strength of a trail will increase as more agents follow that trail. This leads to more rapid successful task completion. In opposition to this the environment enacts upon the sign causing atrophy and entropy to diminish the signal strength. This decay provides the negative feedback ensuring only the most current trails can be sensed and that old trails do not interfere with the task as they become redundant. Stigmergy provides a model of both *active contributions* and *passive interaction* with both varieties being demonstrated within the Web. The two varieties of stigmergy have been categorized as *marker-based* [1] and *sematectonic* [10]. Marker-based stigmergy describes an explicit modification of the environment by leaving a sign with the intention of signaling to other agents. Marker-Based stigmergy is broken into two sub-types: *qualitative* and *quantitative* [1]. The sub-types differentiate where single contributions are sufficient to elicit a response versus an accumulation of contributions increasing the probability of triggering a response as signal strength increases.

In contrast to explicitly leaving contributions, sematectonic stigmergy is defined as a modification to the environment as a by-product of actions being performed. These by-products are occurring inadvertently and unintentionally to the primary task being performed. For example, when considering a path being left in a lawn when people take a short-cut across it they have no intention of signaling to others that they have taken a short-cut. The short-cut is the purpose of the action, but the environment will retain the footstep impact as an alteration of the environment. There is no explicit foot-step left in the environment (obviously excluding cases such as wet feet leaving wet foot prints) however the action has altered the environment and the cumulative foot-step action manifests in the format of a path rather than something recognizable as an aggregation of individual feet traces. These two

varieties of stigmergy highlight the notion of intentionality of communication as being either explicit or implicit [11, 12], with marker-based stigmergy being explicit communication and sematectonic stigmergy being implicit communication.

There has been a significant amount of research focused on stigmergy in robotics and Web environments [5, 13]. Web environments provide a close facsimile to stigmergy in physical environments where a large number of users coordinate in a highly organized manner indirectly communicating through the contributions they make within the Web sites. Our research focuses on how the varieties of stigmergy manifest as Web environment User Interface (UI) elements and how they can be employed within Web site design to improve user collaboration and information categorization. We seek to do this using emerging web modeling technologies.

Web Modelling Language (WebML [4]) is a platform independent way to express the interaction design, data model and business rules of Web application development separately from the implementation platform. WebML permits the formal specification of the data model, interface composition and navigation options. WebML describes a visual notation for designing Web applications that to be exploited by the visual design tool WebRatio for the auto-generation of code. We have implemented proof-of-concept UI mechanisms to record and display both intentional and unintentional web site interaction based on our model of stigmergy that we present in this paper.

#### IV. RESEARCH METHODOLOGY

This research project focuses on identifying the attributes and dynamics of stigmergic behaviour and how it facilitates and benefits the process of recording *active contributions* and *passive interaction* of users when participating in the *grand purpose*. The research is based on a mix-method approach comprised of a literature review content analysis, comparative case studies of existing Web sites, and finally experimentation and data analysis testing the stigmergy design patterns created as part this research.

The literature review has provided a thorough analysis of stigmergy exposing the complexities of the phenomenon and how to best incorporate the properties of stigmergy into a Web environment. The results of the initial analysis stage has led to the development of a model describing the attributes and dynamics of stigmergy along with documentation tracing its components back to the work performed by previous researchers. This provides the chain of evidence to validate the model and enable its correctness to be reviewed.

Due to the qualitative nature of the data collection, a comparative case study approach has been used [2] to provide legitimacy to the repeatability of the research findings. The pattern in the developed model has allowed the comparative case study to be performed against a selection of existing web sites with varying levels of model

alignment. Analysis of the case studies identified common solution patterns as well as *proto-patterns* representing solutions which provide more sophisticated implementation of the stigmergy varieties [3]. Targeting multiple sites for case studies has provided a vital cross section of sites displaying aspects that impact the simplistic entomological examples of stigmergy when applied to complex and cognitive human systems. Targeting multiple sites over a broad spectrum of social aspects of the Web has exposed the repetition of stigmergic patterns further enforcing the generic design of our model.

#### V. PROGRESS TO DATE

The investigative stages of the research plan have been completed including the literature review and initial case study. The literature review includes the analysis of stigmergy as a generic phenomenon and from the perspective of various algorithm designs. Previously [2], we have introduced the resulting model (see Figure 1) of stigmergy including the concept of a stigmergy *grand purpose* and the core components of stigmergy: the *agent*, the *environment*, and the *sign*.

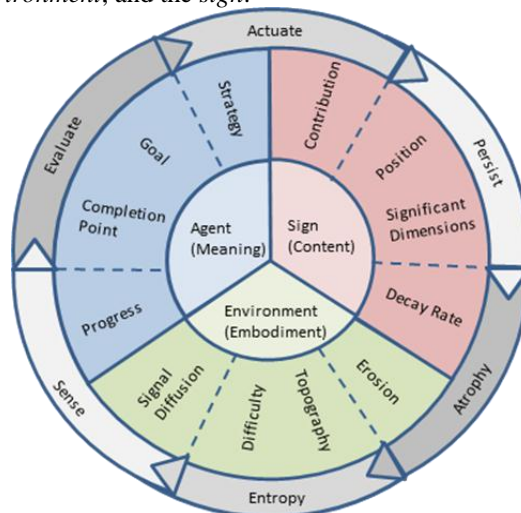


Figure 1. Stigmergy Cycle

Stigmergy facilitates a *grand purpose* (or emergent behaviour) through the *dynamics* (or mechanisms) applied to its inherent *attributes* (or components) of the environment, agents, and artefacts. Our progress to date has provided clarification and the categorisation of virtual pheromones (and other traces) and their role as triggers. The development of our model has provided insight into various similar indirect methods of communication that are considered to be a superset of stigmergy: Behavioural Implicit Communication (BIC). BIC is considered outside of our research area of stigmergic communication. Our modelling of the concepts of implicit and indirect communication mechanisms has provided the missing holistic, conceptual synthesis of the phenomenon. Our intended contribution of analysing the efficacy of stigmergy within Web 2.0 sites will build on this contribution.

The model ties together the core components of stigmergy: an inner band representing the attributes of the components; and an outer band representing the dynamics acting on those attributes. The outer band dynamics are either internal to each component, or defining the interface between components. The model describes the dynamics of equilibrium between positive feedback (contributions) and negative feedback (decay) illustrating how the agent contributes the positive feedback, where the environment applies the negative feedback. This is a generic model of stigmergy that applies for the world of entomology, the human world and the virtual world. This paper focuses on how the varieties of stigmergy manifest as Web environment User Interface (UI) elements; therefore the three components of stigmergy correlate to the users of Web environments, and the contributions that the users make.

To incorporate stigmergy into WebML we need to understand the ways the system receives input and how it should display output. The *contribution* attribute of the model correlates with the user having an input mechanism to *actuate* the contribution to a sign; the *signal diffusion* attribute defines accessibility of an output mechanism presenting the transformed contributions as a signal to users. The environment requires the capacity to store contributions therefore requiring a stigmergy specific data model.

Our research has explored how the different varieties of stigmergy manifest as proto-patterns within the target case study sites [3]. The key concepts identify that there are consistencies between the input (*actuators*) and output (*sensor*) mechanisms for each variety of stigmergy. These findings highlight that the observed Web site cases can be implemented using reusable stigmergic mechanisms.

The two simplest forms of input mechanism for marker-based stigmergy both enable a user to intentionally make a selection, whether as a single presented choice or as a single choice from a number of options. An example of the single presented option can be seen in Facebook with the “Like” feature where there is only one option presented to the user. An example of a single selection of multiple options can be seen in rating systems such as the one-to-five scale within eBay. More accurately the eBay example is a composite set of options where a group of categories are presented (e.g., communication quality, postage costs, etc.) with each choice selection aggregating into a single seller reputation metric. In the case of sematectonic stigmergy, the trigger for the contribution is hidden from the user and occurs unintentionally when the user interacts with site content or navigates to particular pages. An example of this is seen in the Facebook “Seen By” feature that records which users view a particular Group’s news-feed item.

The two simplest output mechanisms observed correspond to signal type: quantitative or qualitative. The Facebook quantitative signal type illustrates how the contributions are transformation into an aggregate summation presented to the user as a “Liked” count. The eBay example provides a metric that is based on a more

complex function but presented as a single percentage value. Our design facilitates both the storage of each of these types of contributions and each type of presentation.

The qualitative signal type is a detailed list of raw contributions and can be seen within the Facebook “Share” feature. The user contribution broadcasts specific content displayed within the standard Facebook news-feed. The contribution is a reference to an article and is stored as a primary key value and specific data model entity name that that key relates to. The actuator input mechanism to record the contribution is the same as for the Facebook “Like” example. The sensor output mechanism of this example is the propagation of the sign to the recipients with accessibility to the signal as defined by *signal diffusion*.

Our most recent progress has been to implement proof-of-concept examples within the WebRatio development environment built on these -generic proto-patterns. The data model for our tests can be considered within three separate components: core entities for application functionality; supporting entities (e.g., user accessibility entities); and stigmergy entities.

Figure 2 shows the user accessibility entities (*user*, *group* and *module*) that are created by default within WebRatio. Also shown is the stigmergy specific data model that maps to the components and attributes as illustrated in Figure 1.

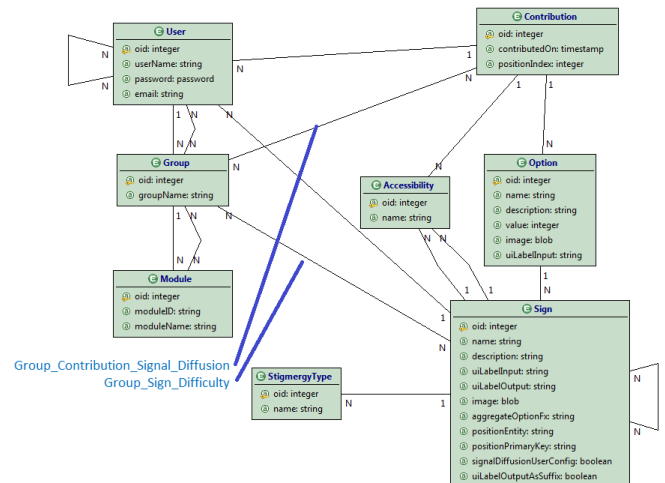


Figure 2. User Accessibility & Stigmergy Positive Feedback Data Model

Our model requires that we add the self-referenced many-to-many relationship to the *user* entity and call the resulting relationship *friends*. It is possible that in future releases this enhancement would become a standard part of WebRatio given current social website networking trends.

The *sign* and *contribution* entities are associated (via Foreign Key) to the *user* and functions as the environmental persistence of the user contributions. The *contribution* is the result of the *option* selected (intentionally) or left (unintentionally) by the user as a byproduct of interaction with the input mechanism. The available options are those which have been defined as being presented for a particular

*sign*. The *difficulty* entity defines the accessibility for to the *actuator* (or input) to particular users of the site, where *signal diffusion* defines accessibility to the *signal sensor* (or output) through the output mechanisms. The *group* entity is related to the *difficulty* and *signal diffusion* entities (resulting from the many-to-many relationships) defining accessibility and enabling users to set their own privacy levels of contributions. The deployment of this feature is dependent on site-specific implementations. For example, Facebook allows users to restrict the accessibility of their “Share” contributions but not their “Like” contributions. The capability to expose these features for one contribution and not the other are implemented in the *sign* definition as a dynamic feature based the stigmergy data model configuration. Finally, we could consider extending the implementation for *position* to include navigable connected graphs based on Web site hyperlinks but the added complexity is outside the scope of this research project.

The data model supports the definition of signs that fit different varieties of stigmergy. Our quantitative, marker-based example (as illustrated by the Facebook “Like” feature) is defined as a single *sign* record (e.g., of “Like”) and a corresponding single *option* record that has a *value* attribute of 1. The *sign aggregationOptionFx* attribute indicates the SUM function for the output mechanism to perform a sum function against to determine the “Like” count. Note: a COUNT function would produce the same result. Given our qualitative, marker-based example we assume that Facebook stores news-feed data in an associated table. The *sign* record defining the sign stores the table name in the *positionEntity* attribute and the name of the primary key field in the *positionPrimaryKey* attribute. This defines the content’s position for news feed articles being liked and how that content is referenced. The *signal diffusion* record for the sign is preset to visible to everyone and the *sign.signalDiffusionUserConfigurable* disabled because Facebook does not allow users to set privacy on who can see that they have liked something; anyone with access to the news-feed article can see the “Like” count. The *contribution* record would then store that a particular *user* deposited the “Like” *option* against a news-feed item that is identified by the primary key value stored in the *positionIndex* attribute. The option should be presented as a single button (or hyperlink) being that there is only a single option in this instance, and is labeled using the string stored in the *sign.uiLabelInput* attribute. The output mechanism queries the stigmergy data and presents the result labeled using the string stored in the *sign.uiLabelOutput* attribute. The differentiation of input and output labels is purely for semantics (e.g., Facebook input is “Like” where the output aggregation is “Likes”). The query is a simple sum function of the *contribution.value* where the *positionIndex* is equal to the current news-feed entry’s primary key.

If we consider the quantitative, marker-based, eBay example for seller-reputation feedback, there is an input mechanism that allows the selection of a single *option* from

multiple options defined against the *sign*. The input mechanism in our proof-of-concept implementation presents a number of options within a drop-down list; however it could also be presented as a radio-button group or a group of buttons / hyperlinks. This *option* presentation is designed into our generic WebRatio output mechanism component and should be dynamic in its ability to render itself according to whether one or many *options* are available for the *sign*. The storage of the contribution remains the same, as does the query used within the output mechanism. A slightly more complex query is required where a composite sign (sign made up of signs) has been defined. The result set is driven by a recursive tree-walk of the *sign* entity generating the collection of *contribution* data grouped by the *positionPrimaryKey* attribute. This applies the sign’s *aggregationOptionFx* attribute named function against the collection of children sign’s *option.value* attribute where multiple contributions exist. This functionality is hidden in the output mechanism and is transparent to both the user and developer. In the case of eBay where feedback appears to be an average or moving average, the output mechanism can be extended enabling the customization of the aggregation function; however the incorporation of more complex though standard functions can easily be included in the default output mechanism.

The Facebook “Share” feature is an example of qualitative, marker-based stigmergy and follows the same pattern where there is single *option* selection that is associated (via Foreign Key described by meta-data in the *sign* entity) against each news-feed article. Corollary the same data for the *contribution* would be stored; however the difference here is that the user is capable of specifying a different visibility level in *signal diffusion* for their individual *contribution* because that feature is offered to the user. The difference with the output mechanism is that the “Share” feature is provided as part of the core Facebook functionality. The sharing of a news-feed item means that it becomes accessible to the subset of users to whom the content has been shared with. The site functionality provides a qualitative listing (rather than quantitative aggregation function) to exploit this particular signal type. In this example the result set is driven by a query selecting data that is visible to the current user where the contributing *user* is related to them as defined by the *friend* entity relationship or *group* entity which they belong to.

The Facebook “Seen By” feature is an example of sematectonic stigmergy and follows the same pattern where a single *option* is stored as the *contribution*. This is the same *sign* and *option* configuration as outlined in the Facebook “Like” and “Share” examples. The only difference is that the user when navigating a hyperlink to specific content triggers the input mechanism unintentionally. The *option* record for the “Seen By” *sign* has a *value* attribute of 1 and has the same results as for the “Like” *sign* count. The input mechanism is associated to a hyperlink with the pre-defined *option* specified for the

contribution. The output mechanism in this example performs the same sum function of the *contribution.value* and where the *positionIndex* is equal to the current news-feed entry's primary key.

WebRatio provides a modeling interface for design a web application. Predefined components are provided which perform the presentation and transactional operations of a Web site. While stigmergy can be incorporated into a site as a design pattern the optimal approach is to provide reusable components performing the *actuator* and *sensor* dynamics of our model thereby providing reusable input and output mechanisms. Figure 3 provides an example of how an *actuator* can be built using standard WebRatio components based on our design pattern.

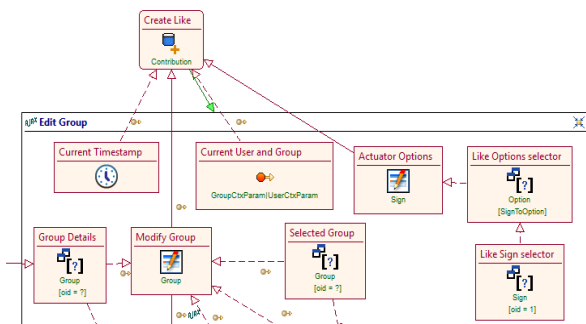


Figure 3. WebML "Like" Sign Actuator design

The example illustrates one way to implement the "Like" sign (predefined within the sign data model entity at primary key oid 1) against a particular group. The *actuator* is located on the page where group entities can be edited and in this example is provided by the link from the Entry Unit named "Modify Group" to the Create Unit named "Create Like". The standard Create Unit is used to insert a record into the contribution entity and the row values area passed in through the links providing values for *contributedOn*, *currentUser*, *currentGroup* and the *option* entity foreign key. The *positionIndex* value is provided using the Link for the currently selected group data entry unit. The specific option to add as the contribution is provided by the Entry Unit named "Actuator Options". The option value is restricted using a Relationship Condition between the "Like Sign selector" and the "Like Options selector". NOTE: In the "Like" stigmergy example only a single option is presented to the user requiring the Entry Unit being configured to not be visible. For examples where multiple options are provided, a Selection Field must be included to present the alternate options within a drop-down list.

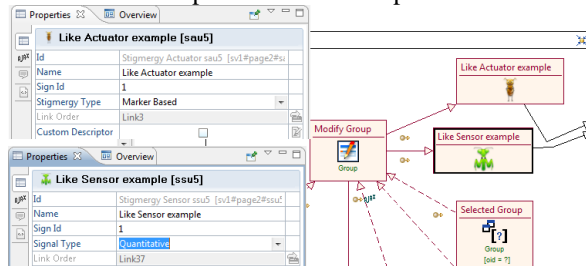


Figure 4. Custom Unit "Like" Sign Actuator design

Figure 4 shows the same example when using our *actuator* Custom Unit within the WebML design. Also shown is our *sensor* Custom Unit. The dramatic simplification is obvious where current user and group values can be obtained within the web service context instead of model links; only the *positionIndex* value needs to be provided via a link. The primary key defining the options for the sign is specified as parameter of the unit, as shown in the Properties window. There is a web service associated with the unit providing database transactions, and more sophisticated algorithms pertaining to the *difficulty* and *signal diffusion* facets of the signal. The final runtime output is displayed in Figure 5.

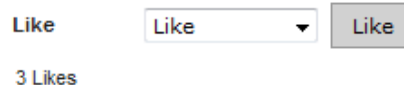


Figure 5. Runtime "Like" actuator and sensor output

### VI. PROBLEMS ENCOUNTERED

WebRatio is a relatively immature product with a small user group and support based. As such there have been a number of problems and impediments encountered.

Custom Units within WebRatio allow definition of page template content to be customized (using scripts) at page generation time, while mark-up tags enable dynamic content during page population at runtime. The limited available tutorials for WebRatio have impeded our progress in optimizing our *actuator* and *sensor* units' implementation. A specific example can be seen in Figure 5 where the runtime *actuator* instance displays a drop-down list containing "Like" and also a button labeled "Like". Our optimal design requires the capacity at page generation time to determine whether a specific sign has a single option, or multiple as defined in the *option* entity. Based on the result of this database query either a single button or a button with the drop-down list would be presented. At present only Custom Unit design-time properties such as the *SignId* as seen in Figure 4 have successfully been prototyped as available at page generation time. A simple work-around for our proof-of-concept has been to split our *actuator* into three separate Custom Units: marker-based (single option), marker-based (multiple options) and sematectonic based. The same applies for our *sensor* design where the Custom Unit split is based on signal type: quantitative and qualitative. Rather than rely on the work-around (which merely means the appropriate Custom Unit be selected for the associated sign data) we pursue the implementation of the consolidated *actuator* and consolidated *sensor* designs. Resolving this issue will also facilitate removing superfluous Custom Unit design-time properties of Stigmergy Type (for *actuator*) and Signal Type (for *sensor*), as they are also defined within the data model. Ideally we will succeed in accessing the stigmergy data model content to define these page qualities at page generation time. However, if we realize that this is not achievable within the WebRatio tool it does not impinge on the correctness of our

model or future experiments on the efficacy of including stigmergy in Web sites.

Since development of the *actuator* and *sensor* prototypes, we have reflected on potential design deficiencies when considering stigmergic mechanisms deployed against our case study Web sites. We have identified two areas for improvements: the ability to revoke a contribution (such as “Unlike” within Facebook); restricting accessibility to the *actuator* after a single contribution (such as providing transaction feedback within eBay). Both of these enhancements can easily be achieved by adding Boolean fields *userRevokable*, (as Boolean) *uiLabelRevoke* (as String) and *singleContribution* (as Boolean) to the sign entity. The *singleContribution* value will define additional accessibility to the *actuator*, and will provide alternative labeling for revocable contributions.

Progress so far only covers the user-centric dynamics (e.g., *actuate* and *sense* making) of stigmergy that provides the positive feedback system. To fully exploit stigmergy we must also implement the negative feedback illustrated as *atrophy* and *entropy*. WebML and WebRatio provide system events to trigger actions that can drive these environment-centric dynamics. Inclusion of these mechanisms into our proof-of-concept will complete our implementation by introducing the balancing negative feedback of stigmergy. We have yet to address some attributes presented in Figure 1: Progress, Goal, Completion Point, and Significant Dimensions. These attributes pertain to user-centric data (e.g., stored in users heads) and as such are arbitrary as to whether sites facilitate the recording and inclusion of such data. We anticipate addressing these issues in the future.

## VII. CONCLUSION AND FUTURE WORK

Stigmergy can be seen throughout entomological, human and Web environments. Stigmergy provides a set of dynamics that facilitate a balance between positive and negative feedback within a system. Previously we have presented papers defining *what* stigmergy is. This paper presents *how* the positive feedback mechanisms of stigmergy can be architected into web sites incorporating reusable User Interface components. We have designed a data model supporting each stigmergy variety. Our generic implementation of input and output mechanism within WebRatio demonstrates the simplest examples of stigmergy.

We continue to refine our implementation of positive feedback mechanisms by addressing problems encountered during initial prototype development. Immediate future work is required to consolidate our sensor and actuator units. This requires resolving whether our chosen development environment is technically capable of allow database querying at page generation time, and not solely page population time. We intend to extend model functionality where a Web site design enables user revocation of a contribution or provides a restriction to single, irrevocable contributions. Further model validation

will occur by developing prototypes encompassing stigmergy examples observed in alternative case study sites thereby, extending on our Facebook-centric examples. Finally we must extend this data model and include mechanisms that provide negative feedback.

Our proof-of-concept will be used to create an experimental Web site testing user interaction. The analysis will determine how best to employ stigmergy in site designs and assess if stigmergy improves user coordination.

## REFERENCES

- [1] G. Theraulaz and E. Bonabeau, "A Brief History of Stigmergy," *Artificial Life*, vol. 5, pp. 97-116, 1999/04/01 1999.
- [2] A. Dipple, "Stigmergy in Web 2.0: a Model for Site Dynamics," in *ACM Web Science 2012*, Evanston, 2012, pp. 116-124.
- [3] A. Dipple, K. Raymond, and M. Docherty, "Extending Web Modeling Language to Exploit Stigmergy: Intentionally Recording Unintentional Trails," in *WEB 13, The First International Conference on Building and Exploring Web Based Environments*, Seville, Spain, 2013, pp. 87 - 92.
- [4] S. Ceri and P. Fraternali, "Model for the definition of world wide web sites and method for their design and verification," US6591271 B1, 2003.
- [5] H. Van Dyke Parunak, "A Survey of Environments and Mechanisms for Human-Human Stigmergy," in *Environments for Multi-Agent Systems II*, ed, 2006, pp. 163-186.
- [6] Z. Mason, "Programming with stigmergy: using swarms for construction," in *ICAL 2003: Proceedings of the eighth international conference on Artificial life*, 2003, pp. 371-374.
- [7] P.-P. Grasse', "La reconstruction dun id et les coordinations interindividuelles chez Bellicositermes natalensis et Cubitermes sp., La theorie de la stigmergie: Essai d'interpretation du comportement des termites constructeurs," *Insectes Sociaux*, vol. 6, pp. 41-80, 1959.
- [8] E. Bonabeau, M. Dorigo, and G. Theraulaz, *Swarm Intelligence: From Natural to Artificial Systems*. New York: Oxford University Press, Santa Fe Institute Studies in the Sciences of Complexity, 1999.
- [9] M. Baumgarten, K. Greer, M. D. Mulvenna, K. Curran, and C. Nugent, "Utilizing Stigmergy in Support of Autonomic Principles," in *Third International Conference on Semantics, Knowledge and Grid*, 2007, pp. 98-103.
- [10] E. O. Wilson, *Sociobiology: The New Synthesis*, Twenty-Fifth Anniversary Edition ed.: Belknap Press of Harvard University Press, 2000.
- [11] L. Tummolini and C. Castelfranchi, "Trace signals: the meanings of stigmergy," in *E4MAS'06 Proceedings of the 3rd international conference on Environments for multi-agent systems III* Hakodate, Japan, 2007, pp. 141-156.
- [12] L. Tummolini, C. Castelfranchi, A. Ricci, M. Violi, and A. Omicini, "'Exhibitionists' and 'Voyeurs' Do It Better: A Shared Environment for Flexible Coordination with Tacit Messages," in *In 1 st International Workshop on Environments for Multiagent Systems. LNAI, n.3374*, ed, 2004, pp. 215-231.
- [13] M. den Besten, L. Gaio, A. Rossi, and J.-M. Dalle, "Using Metadata Signals to Support Stigmergy," in *SASOW '10 Proceedings of the 2010 Fourth IEEE International Conference on Self-Adaptive and Self-Organizing Systems Workshop 2010*, pp. 131-135.