Pervasive Self-Organisation

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Abstract

Humans have probably always been trying to organise the world around us, and we have accounts from at least Aristotle to formalise organisation systems [1]. While this has largely been a manual effort (cf. Linnaeus' Systema Naturae), technological advances in natural language processing and the advent of the Semantic Web research domain have made (semi-)automatic organisation of knowledge about the world possible [2]. Now, on-the-fly DNA sequencing, nanoprocessors, nanosensors, nanobots, and smart surfaces are enabling organic self-organisation of real-world objects. In this paper, we present the theoretical framework and first experiments that ring in this new era of dynamic auto-taxonomising.

Keywords

self-organisation, nanocomputing, Digital Twins, DNA sequencing.

Disclaimer: This paper is a work of fiction, written in 2023 and describing research that may be carried out in 2043. For this reason, it includes citations to papers produced in the period 2024-2043, which have not been published (yet); all citations prior to 2024 refer instead to papers already in the literature. Any reference or resemblance to actual events or people or businesses, past present or future, is entirely coincidental and the product of the author's imagination.

1. Introduction

The organisation of knowledge has largely been a virtual effort - but advances in the Digital Twins [3], coupled with on-the-fly DNA sequencing now enable high-dimensional representation of real-world objects. As we can capture and represent key characteristics from real-world objects and connect that to information about the objects from nanosensors either embedded in the object or surrounding it, we can get a high-dimensional representation of the object as was shown recently in [4]. Our main contribution is to link these representations to common sense knowledge graphs and nanorobots such that objects can self-organise, according to what the situation requires, i.e. objects can move autonomously to group themselves with the most similar other members of the group according to dimensions relevant to a task such as creating a healthy and tasty meal or a personalised museum tour. In this paper, we present a framework and two case studies for self-organisation of items in the real world.

The remainder of this paper is organised as follows. Related work is discussed in Section 2. We present our experimental setup in Section 3 followed by our use cases in Section 4. The

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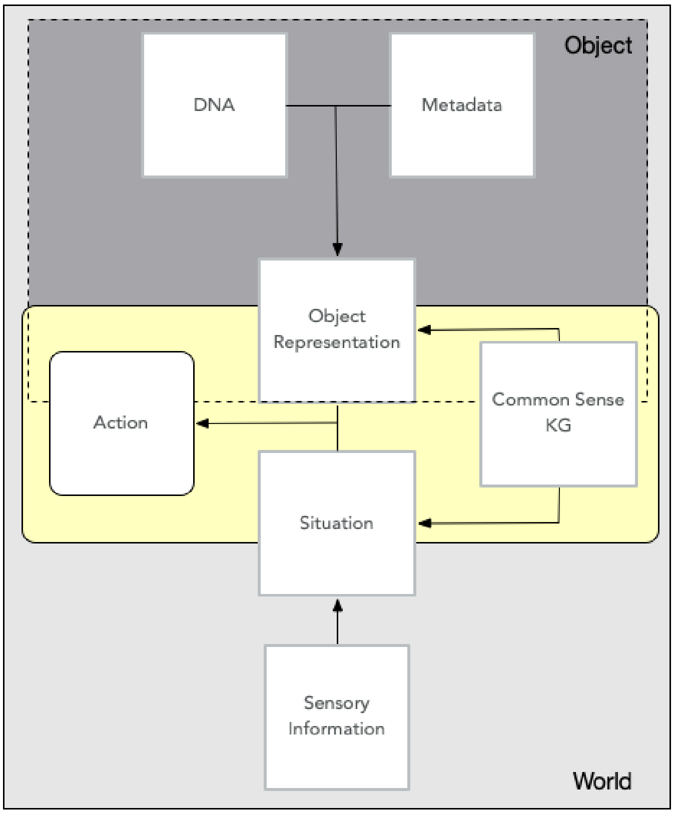

Figure 1: Schematic overview of the self-organising framework with out main contribution highlighted in yellow

results of our experiments are presented in Section 5 and we conclude with a reflection on the strengths and limitations of our approach and future work in Section 6.

2. Related Work

The future of nanoprocessors, nanorobots, and DNA sequencing is a subject of intense research and development in many academic fields [5]. One paper explores the design and optimization of DNA-based nanoprocessors for complex computing tasks [6]. Another study demonstrates the use of nanorobots for targeted drug delivery and cancer therapy [7]. The field of DNA sequencing is also advancing rapidly, with recent studies showing the potential of nanopore technology for high-throughput sequencing with low error rates [8]. With continued advancements in technology and research, the future of nanoprocessors, nanorobots, and DNA sequencing holds immense promise for improving healthcare, environmental monitoring, and other critical fields.

Whereas most autonomous motion mechanisms have involved nanorobots, smart surfaces as successfully implemented by [9] now enable seamless and organic transfer of objects across space.

3. Experimental Setup

In both our use cases, we take a set of real-world objects. Each of the objects are fitted with a non-invasive nucleid acid sample extractor patch that directly feeds the sample into a 16th generation PromethION DNA sequencer.[1] The object's DNA profile and metadata and common sense knowledge from the Common Sense KG [10] together form the Object Representation. The Situation in which the object is to be organised is shaped by sensory information that is embedded in all surfaces and objects since MacGyver and Boothroyd's breakthrough in integrating nanosensors into practically all surfaces in 2035 [11] and the Common Sense KG. Where the object and the situation meet, an action is set in motion that moves the object towards the correct category. Depending on the type of object, this is set in motion by a moving mechanism that is part of the object or part of the object's immediate surroundings. Figure 1 presents a schematic overview of our self-organising framework.

In each of the use cases, the real-world objects are presented with four realistic scenarios. We measure how many of the objects are categorised correctly according to domain experts. We reflect on how efficient the categorisation took place with respect to the moving mechanism, although we remark that success and efficiency of the motion depends on many variables, such as the quality of the moving mechanism, the available space, and control mechanisms for avoiding object collisions [12].

4. Use cases

Many objects and entities in the world have multiple uses and their classification depends on in which setting they are considered. This brings about the need for dynamic classifications, but doing this manually is highly time-consuming. Our two use cases: fruity vegetables and artworks, show how high-dimensional information integration coupled with nanorobots, genetic modification and smart plastics for autonomous spatial re-organisation can make objects seamlessly adjust to different settings.

Use Case 1: Fruity vegetables

Botanically, tomatoes are fruits. But any cook worth their salt knows that tomatoes do not belong in a fruit salad. Other fruits that share this ambiguity are aubergines, avocados, bell peppers, cucumbers, and various squashes. In this use case, we test how well fruits and vegetables can be categorised and moved automatically according to scenarios that involve information regarding their botanical classification, allergens and nutritional characteristics, how they grow and their environmental impact, and their cultural significance. We obtained 226 different servings of fruit and 100 servings of different vegetables on offer at a local supermarket. The experiments were carried out in the industrial kitchen section of our research lab in which the fruits and vegetables were placed on one side of the counter and needed to be categorised and moved to different bowls according to the scenarios. The following scenarios are tested:

[1]https://nanoporetech.com/products/promethion Last visited: 24-03-2043

(a) Smart surface reshaping counter

(b) Autonomous bowl

(c) Genetically modified aubergine on wheels

Figure 2: Different autonomous motion methods that we tested in a kitchen setting

Fruit salad: 100 fruit salad recipes were generated by GPT-48. Recipes had to contain at least 4 different fruit ingredients. In each of the recipes, we blanked out two ingredients for which the system had to provide the blanked out ingredient or a suitable substitute;

Allergy diets: The system had to put together 3x20 healthy meals (breakfast, lunch, and dinner) according to the world health organization's nutritional diet guidelines. The three diets were: a nightshade allergy, pollen fruit syndrome, and latex-fruit syndrome;

Seasonal planting schedule: Aspiring fruit and vegetable growers often find it difficult to choose when to plant what with the abundance of different types of fruits and vegetables and micro-climates. The system's task here was to generate a year-plan for growing 6 different types of fruits and vegetables on a 2x2m plot for 10 different locations across Europe and the Global South;

Usage in cultural feasts: Many cultural traditions revolve around food, many customs involve consuming certain foods (e.g. Oktoberfest), but in some cases other activities are employed such as at the La Tomatina Festival in Spain that has been held since 1975. Finding a balance between honouring cultural traditions, food waste, and health recommendations can be a challenge. In this task, the system had to find the least environmental and health burdening alternatives for 10 different international food festivals which could include a faster growing variety of a particular food or an alternative that could be reused as biofuel. The answers to this task were evaluated by a panel of experts from City University, London's Centre for Food Policy.

We test three different motion mechanisms in our scenarios, as shown in Figure 2. It should be noted that the genetic modification of objects to make them move of their own accord is currently only allowed in BSL-2 research labs.

4.1. Use Case 2: Artworks

There are many ways to regard and organise artworks. Up until 2028, most galleries organised their artworks according to the time and location in which the work was created. Spurred

Figure 3: View of the Steels Gallery with motion grid

by immersive technology advancements, most notably [13], Rijksmuseum Amsterdam started organising its galleries thematically, and Louvre and the Met soon followed [14].

For this use case, we teamed up with the Steels Gallery in Brussels due to their state-of-the-art robotics gallery organisation system. Whilst generally curators draw up the wall plan for the gallery, we connected RoboGalleryOrg® to our self-organisation system to rearrange artworks in the gallery according to our scenarios. In Figure 3 a view of the gallery with paintings organised on the grid along which the robot movers move is depicted.

For this use case, we designed the following scenarios for which all artworks on display in the gallery are used (365 paintings and 115 sculptures). These experiments were carried out during the nights when the gallery was closed and concerned the following scenarios:

Classical organisation: When the museum first opened in 1925, the collection was organised according to period and place of the creation of the artwork. The original gallery plan serves as a gold standard, which the system needs to reproduce from the artworks' metadata and the Common Sense KG;

Material types: There are many differences between the different paints and other materials used. Older paints may include lead, mercury, cobalt and barium and other substances that are not used anymore. For some sculptures, the materials are alloys that are not easily defined by the naked eye. In this scenario, the system needs to organise the art objects according to an analysis of their chemical components [15];

Depicted actions: With computer vision methods having reached a stage where scenes and

Table 1
Precision, recall and F_1 results of the fruity vegetables use case on the four scenarios

Scenario	Precision	Recall	F_1
Fruit salad	86.78	83.33	85.02
Allergy diets	90.00	98.00	93.83
Planting schedule	63.54	55.80	59.41
Cultural feasts	86.77	50.01	63.45

individual elements thereof can be recognised reliably across all genres of images, along with for art-historical images their cultural background and meaning (for example for allegories), this scenario challenges the system to organise the artworks by depicted actions according to Framenet frames [16];

Spectrum of gruesomeness: Not all artworks are pleasant or suitable to all audiences. In this scenario, the mood of artworks based on topic, colours are combined into a gruesomeness score that categorises paintings by suitability to certain audiences using a classification system akin to the Motion Picture Association film rating system adapted to the art world.[2]

5. Results and Discussion

The results in Table 1 show that the system performs best on the fruit salad and allergy diets scenarios. This is not surprising as the categorisation there is more clear cut: when an allergen is present, the object should not be included. The planting schedule and cultural feasts scenarios are more challenging as there the system has to contend with more variables. For cultural practices holds that they are (still) less well represented in structured knowledge bases. The complexity of weather systems and micro-climates affected the system negatively in planting schedule scenario, although it should be said here that the system was often close i.e. getting the main species correct but not the subtype.

As for the three different motion mechanisms (smart surface reshaping counter, autonomous bowl, genetically modified wheel-growing), the autonomously moving bowl was the slowest of the motion mechanisms. This is probably due to the different bowls having to navigate around each other and pick up new fruits and vegetables in each run. This problem is exacerbated in scenarios with many different objects needing to move around. The smart surface reshaping counter flexed itself to however many categories and objects had to be re-organised whilst the genetically modified objects wheels' do not work well for larger fruits and vegetables such as melons and pumpkins. Genetic modification is also the least flexible option when it comes to navigating different surfaces as it would require a different modification which can only be achieved in the next crop.

The results in Table 2 illustrate the clear strengths of DNA-sequencing, namely in analysing materials for the Material types scenario. The Classical organisation scenario is well understood and relatively doable too. The system stumbled on the scenarios that require more interpretation

[2]https://www.museumsassociation.org/artwork-rating-system

Table 2
Precision, recall and F_1 results of the artworks use case on the four scenarios

Scenario	Precision	Recall	F_1
Classical organisation	78.99	85.00	81.88
Material types	97.88	95.66	96.76
Depicted actions	65.83	63.72	64.76
Gruesomeness	59.99	64.89	62.34

of the artwork, especially in less realist artworks the system suffered on the Depicted actions scenario. Gruesomeness is also considered subjective [17], and different colours can mean different things in different settings. The more monochrome, darker, greyish artworks were classified correctly fairly easily, but a painting such as Munch's The Scream still confused the system. It should also be noted that physically moving the 480 artworks into a new grouping takes time as the objects need to move along a grid and cannot move too fast to prevent damage.

6. Conclusion & Future Work

We have shown that it is possible to design a system where real-world objects self-organise - thus taking information organisation out of the virtual world and bringing it into the real world. We tested two use cases on four scenarios each and showed that to a large degree objects can self-organise in a real-world setting with currently available technology. There are some limitations and concerns. Large objects such as trees should only self-organise in carefully controlled settings to avoid innocent hikers getting trampled by ent-like self-organising trees. For the Allergy diets scenario, it is of utmost importance that the system return no false negatives as this could lead to life-threatening situations. Furthermore, regulations and safety precautions around self-moving objects are still evolving [18].

Self organisation also profoundly changes the role of knowledge engineers: their work will focus more on steering self-organising systems and interpreting resulting categorisations and less on actually organising objects and information. While manual knowledge organisation will not entirely disappear, self-organisation will open up new ways of thinking about the relationships between objects and their properties.

Current analysis, sensor and DNA-sequencing technology cannot capture all dimensions of objects, there is therefore still work to be done to create true digital twins. Lastly, we cannot yet place the necessary sensors and analysis tools on liquids and gases, but directing oceans for clean energy and removing air pollution would be very useful use cases of this type of technology. We identify this as an interesting avenue of research to tackle for ESWC 2063.

CRediT statement:

MvE: Conceptualization, Methodology, Project administration, Writing - review & editing. CG: Writing - related work section. MB: Visualisation (Fig. 2 & 3).

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