Lecture Notes in Networks and Systems 268

Matteo Zallio
Carlos Raymundo Ibañez
Jesus Hechavarria Hernandez *Editors*

Advances in Human Factors in Robots, Unmanned Systems and Cybersecurity

Proceedings of the AHFE 2021 Virtual Conferences on Human Factors in Robots, Drones and Unmanned Systems, and Human Factors in Cybersecurity, July 25–29, 2021, USA

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Preface

This book deals with two areas of critical importance both in the digital society and in the field of human factors: "Robots, Drones and Unmanned Systems" and "Human Factors in Cybersecurity". Researchers are conducting cutting-edge investigations in the area of unmanned systems to inform and improve how humans interact with robotic platforms. Many of the efforts focused on refining the underlying algorithms that define system operation and on revolutionizing the design of human–system interfaces. The multi-faceted goals of this research are to improve ease of use, learnability, suitability, interaction, and human–system performance, which in turn will reduce the number of personnel hours and dedicated resources necessary to train, operate, and maintain the systems. As our dependence on unmanned systems grows along with the desire to reduce the manpower needed to operate them across both the military and the commercial sectors, it becomes increasingly critical that system designs are safe, efficient, and effective and provide humans with reliable solutions to daily challenges. Optimizing human–robot interaction and reducing cognitive workload at the user interface require research emphasis to understand what information the operator requires, when they require it, and in what form it should be presented, so they can intervene and take control of unmanned platforms when it is necessary. With a reduction in manpower, each individual's role in system operation becomes even more important to the overall success of the mission or task at hand. Researchers are developing theories as well as prototype user interfaces to understand how best to support human–system interaction in complex operational environments. Because humans tend to be the most flexible and integral part of unmanned systems, the human factors and unmanned systems' focus considers the role of the human early in the design and development process in order to facilitate the design of effective human–system interaction and teaming. This book addresses a variety of professionals, researchers, and students in the broad field of robotics, drones, and unmanned systems who are interested in the design of multi-sensory user interfaces (auditory, visual, and haptic), user-centered design, and task–function allocation when using artificial intelligence/automation to offset cognitive workload for the human operator.

This book additionally deals with the role of the human factors in cybersecurity. It is in fact the human element what makes the cyberspace complex and adaptive. According to international cybersecurity reports, people are both an essential part of the cybersecurity challenge and part of its solution. Cyber-intrusions and attacks have increased dramatically over the last decade, exposing sensitive personal and business information, disrupting critical operations, and imposing high costs on the economy. Therefore, understanding how people behave in the digital environment and investigate the role of human error in security attacks is therefore fundamental for developing an effective approach to cybersecurity in a variety of contexts. This book gathers studies on the social, economic, and behavioral aspects of the cyberspace and reports on technical and analytical tools for increasing cybersecurity. It describes new educational and training methods for management and employees aimed at raising cybersecurity awareness. It discusses key psychological and organizational factors influencing cybersecurity. Additionally, it offers a comprehensive perspective on ways to manage cybersecurity risks for a range of different organizations and individuals, presenting inclusive, multidisciplinary, and integrated user-centered design approaches combining technical and behavioral elements. As editors, we hope its informative content will provide inspiration, leading the reader to formulate new, innovative research questions, applications, and potential solutions for creating effective human-centered solutions by teaming with robots and unmanned systems.

Contributions have been organized into five sections:

Human Factors in Robots, Drones and Unmanned Systems

1. Human Factors and Unmanned Aerial Vehicles
2. Robots in Transportation Systems
3. Drones, Robots and Humanized Behaviors
4. Robotic Systems for Social Interactions

Cybersecurity

5. Human Factors in Cybersecurity

Each section contains research papers that have been reviewed by members of the International Editorial Board. Our sincere thanks and appreciation to the board members as listed below:

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Contents

Human Factors and Unmanned Aerial Vehicles

Concept for Cross-platform Delegation of Heterogeneous UAVs in a MUM-T Environment

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Abstract. In this article we present a new approach enabling human pilots to delegate and negotiate tasks with other human pilots in Manned-Unmanned Teaming (MUM-T) missions. This incorporates a concept for cross-platform delegation of tasks during missions, bridging different hierarchical leadership levels. So far, we focused on a single human user guiding several unmanned systems. Within this scope we will consider human cooperation to enable the delegation of tasks between several MUM-T compounds on a systems-of-systems level. The methods we already use to delegate tasks within a single MUM-T package will now be extended by delegating tasks from one system to other systems, coordination between packages and situation-dependent deployment of UAVs from another MUM-T compound, all supervised and coordinated by the highest hierarchical instance in the overall structure. Results from initial expert feedback sessions showed that the presented concept represents an early, but already valid approach. However, revisions are still needed concerning the interaction between the human users and the technical functions.

Keyword: Cross-platform · Mission planning · Task delegation · Manned-unmanned teaming

1 Introduction and Background

MUM-T missions facilitate teams of manned and unmanned systems. These compounds consist of at least one manned vehicle and at least one unmanned vehicle, both controlled by the human cockpit crew aboard the manned aircraft. A field of research deals with the mission planning and management of several unmanned vehicles or aircraft by a single human during the execution of highly dynamic missions [1, 2]. As a starting point for the conception and design of a MUM-T technology solution, we conduct a work process analysis followed by a work system cognitive design according to [3]. The work system notation provides a graphical and semantic description language to create a top-level system design for complex Human-Autonomy Teaming (HAT) systems. This results in the following (Fig. 1) system for MUM-T missions.

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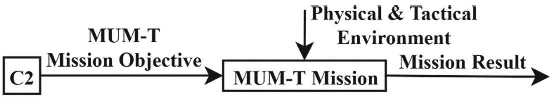

Fig. 1. Work process for MUM-T missions

The Work Process (*WProc*) represents the MUM-T Mission to be performed and it receives its Work Objective (*Wobj*) "MUM-T Mission Objective" from the Command and Control (C2) center. The *WProc* is embedded in a Work Environment (*WEnv*) providing various inputs, which are information from the physical and tactical environment. The information or physical effects generated by the *WProc* – the Work Process Output (*WPOut*) – are the Mission Result. According to the *WProc* defined in Fig. 1, the corresponding initial Work System (*WSys*) design is shown in Fig. 2.

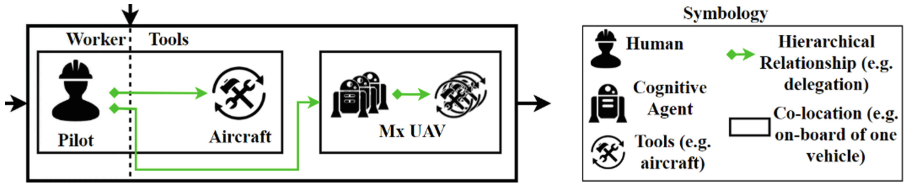

Fig. 2. Work system for task based guidance

A *WSys* is facilitated by two different roles, the **Worker** and the **Tools**. The **Worker** knows, understands, and pursues the *WObj* by own initiative. The **Tools** receive tasks from the **Worker** and will only perform when told to do so. **Tools** are in most cases conventional automated systems, like vehicles including conventional automation. In addition, there shall be **Cognitive Agents** in a *WSys* which understand the tasks delegated by **Workers** and can realize those tasks by using their dedicated **Tools**. Currently, we investigate the guidance of several Unmanned Aerial Vehicles (UAVs) from the cockpit of aerial vehicles in the fast-jet and helicopter domain [4, 5]. In both domains, the cockpit crew is responsible for the delegation of tasks to the unmanned team members and the monitoring of the mission execution, in addition to the conventional pilot tasks. Therefore, we developed our Task-Based Guidance approach according to [6], where the cockpit crew delegates tasks to the cognitive agents on board the UAVs using dedicated interfaces. In previous studies, our work focused on guiding a small number of UAVs from aboard a single manned platform [7]. Here the pilot specifies the tasks to be performed during the mission, assigns them to his unmanned team members with the help of a Tasking Interface (**TI**) and creates a mission plan. The result is displayed in the same interface that is used for task delegation. The described approach was implemented in our research simulator and experimentally evaluated by use of a single fast-jet with a single-seat cockpit. The experiments were performed with pilots of the German Air Force. The exact execution of the experiment and the results are contained in [8].

2 Problem Definition

In large-scale military air operations, several teams – also called packages – consisting of different aircraft with different subtasks work together to achieve a common overall mission objective. This is achieved through a so-called Composite Air Operation (COMAO). Within a COMAO, a distinct hierarchy and responsibility of the individual participant exists. In general, there are three roles with dedicated tasks within a COMAO which must be assumed by the team members who are in the air [9]. The Mission Commander (MC) has the overall view of the mission and acts as the superior planning authority in the air. One hierarchical level below, the Flight Leads (FL) are deployed in different packages with different mission subtasks. On the lowest level in a COMAO are the individual team members who have to fulfil their specially assigned tasks by using their own abilities. These so-called wingmen are usually manned aircraft, however, will be replaced by UAVs in our MUM-T mode of operation (Fig. 3). Applying the work process and work system analysis to a COMAO and only look at the MC and one FL, then one gets the WProc shown in Fig. 4.

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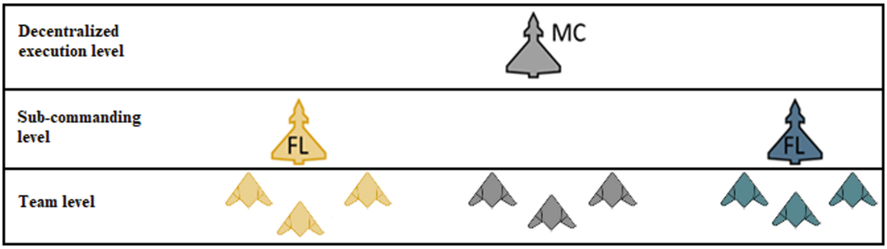

Fig. 3. COMAO using a MUM-T approach

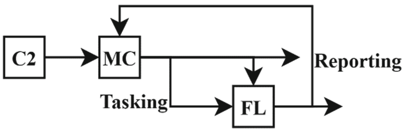

Fig. 4. Work process for a COMAO, only MC and one FL considered

Currently, in air operations the communication between the MC and the FLs is mainly voice based. In MUM-T, an additional channel for task delegation via voice commands can be incoherent with the previously mentioned modes of operation concerning the unmanned assets, and therefore, in total complex and potentially too demanding for the user. Furthermore, with Task-Based Guidance of UAVs [8] and Task-Based Guidance of the own aircraft, this would lead to a major break and heterogeneity in the interactions of the pilots in the cockpit in our MUM-T mission management tools. Therefore, the aim is to apply our approach of Task-Based Guidance, which was proven extremely useful for manned to unmanned delegation [8], for manned to manned delegation as in a COMAO. This gives a type of task delegation between pilots that corresponds to the leadership of the UAVs. This provides a uniform and general mission management while executing MUM-T missions on COMAO level. In this context we speak of cross-platform delegation interfaces.

3 Concept

The first step is the top-level design of the *Work System* as shown in Fig. 5.

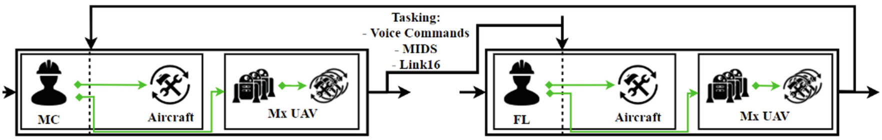

Fig. 5. Work system COMAO

The MC receives the main mission objective and corresponding sub-mission objectives from C2 as *WObj* (see Fig. 4) and provides them to the FL as part of his *WPOut*. During the mission execution, the MC receives information from the environment and from the FL. Based on this information, the MC can delegate new tasks to the FL which complement their individual mission objectives. The described system can of course be extended by any number of FLs, depending on the mission requirements. The *WSys* shows the complexity of the tasking interactions of the MC which are threefold: (1) flying his tactical aircraft by use of conventional flight control and flight guidance interfaces (potentially in the near future also by a task-based approach), (2) managing a team of UAVs by use of a dedicated TI, (3) delegating tasks to other manned or manned-unmanned flights mainly by use of voice communication, but also supported by a rather inflexible data-link system (e.g. MIDS/Link 16). Our approach is to integrate all these activities to a single, cockpit integrated delegation manager, which provides a unified mode of interaction for the three mentioned channels. Therefore, we suggest the task-based method and interaction design that we widely used for UAV-delegation. This leads to a *WSys*, which can be seen in Fig. 6.

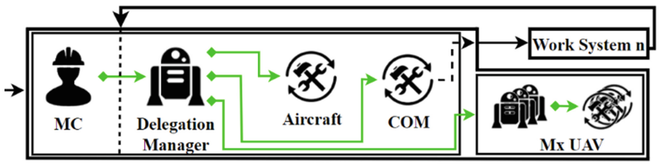

Fig. 6. WSys with delegation manager

The tasks defined by the MC are passed to a cognitive agent, the so-called Delegation Manager **(DM)**, via appropriate interfaces. The DM shall unify and comprise the interaction modes in a single framework and support the formulation and routing of tasking dialogues. This agent can then determine a suitable recipient for the task to be delegated and send it to this receiver. Furthermore, to the DM supports the coordination of the individual MUM-T packages in order to carry out coordinated operations if necessary. This is achieved by inserting and parameterizing constraints between planned tasks. Some parts of the described concept have already been implemented and are described in the following section.

4 Implementation and Early Results

With the existing research simulator (a full hardware and software setup for solving and validating of concepts and hypotheses with human-in-the-loop experiments), it is possible to execute full military air operations with a single MUM-T compound, consisting of one human in a single-seat aircraft and any numbers of UAVs. This has been extended to execute missions on COMAO level with multiple MUM-T packages. After the hard- and software extensions (additional complete simulation environments and cockpits, as well as the possibility to exchange data between the systems), a simulation mission was created deploying three MUM-T packages and two aircraft (one single seat and one dual seat). Each package consists of one human and three UAVs. One of the humans assumes the role of MC (inside the rear-cockpit of the dual-seat aircraft) and the other two act as FL, both in the front-cockpits of their aircrafts. FLs can delegate tasks to their own team members using the existing functionalities and interfaces (see Fig. 7).

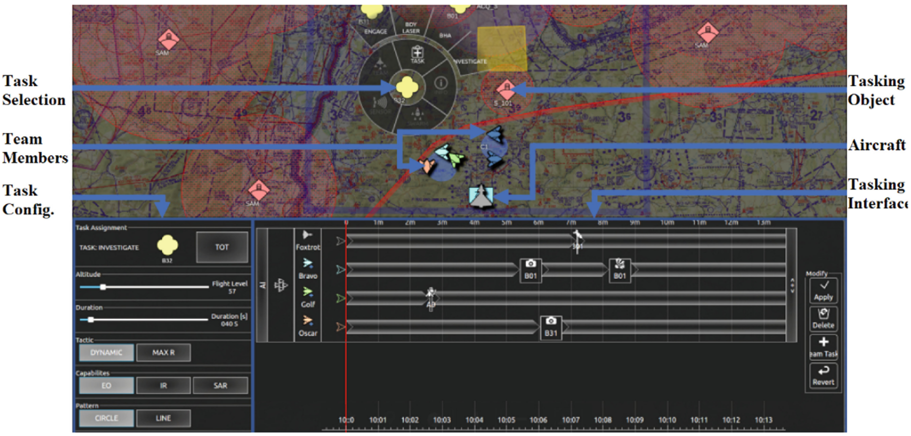

Fig. 7. Cockpit interface section with tactical map and TI

After selecting a Tasking Object, the Task Selection opens, where a suitable task can be selected. Afterwards the TI opens. Here, the task can be delegated to the Team Members or the own Aircraft. The resulting mission plan with the assigned tasks (boxes in the TI) is also shown in the TI. If necessary, the individual tasks can be configured more precisely in the Task Config. For the MC, to have a full overview of the mission, its progress, and to delegate tasks to the FLs, the TI has been extended to allow the MC to additionally see the other packages (Fig. 8), while the FLs have the view above.

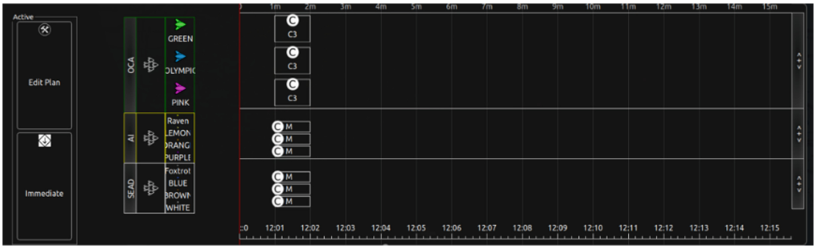

Fig. 8. TI MC

In addition to the process described above, the MC has the option of delegating tasks to the FLs beyond the boundaries of his own compound. This process is shown in Fig. 9.

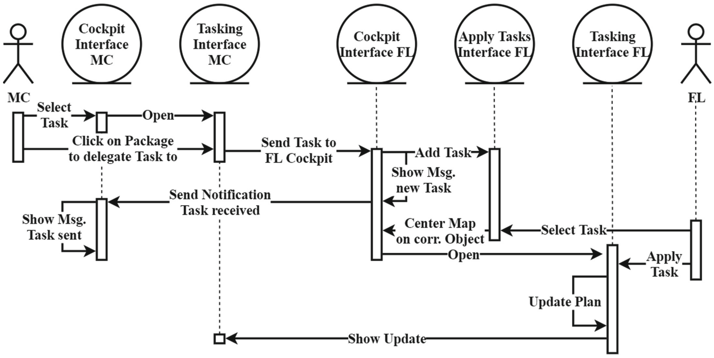

Fig. 9. Sequence for delegating tasks from MC to FL

The MC selects a task in his cockpit interface, whereupon his TI opens. Now he chooses the Package to delegate the task to. The task is sent to the receiver cockpit, and a message is displayed to the recipient and sender indicating that the task has been received or successfully sent. At the same time, the sent task is added on a dedicated interface on the receiver's side. The FL can select the task from this interface, which centers his map in the cockpit interface on the corresponding target object and opens the TI. After adding the task to the mission plan, it is updated and the MC will also see the updated mission plan of the corresponding FL in his TI. Depending on the overall-situation and the workload of the FLs, it would be conceivable that the MC could also insert and/or parameterize tasks directly in the mission plan of the other packages, for example to facilitate coordinated maneuvers.

5 Conclusions and Outlook

Initial experiments with test persons - including German Air Force pilots - showed that the current implementation of the TI for the MC can become confusing, especially for more complex, longer missions. Another aspect that needs to be examined and revised is the time required by the planning algorithm to create mission plans that become more and more complex as the mission duration increases. Basically, the current concept and implementation allows to carry out proven missions consisting of one MUM-T system, which have been extended to the corresponding configuration with three MUM-T systems. The direct insertion and parameterization of tasks by the MC into the FL's mission plan and the DM's capabilities still need to be fully defined, implemented as well as evaluated through meaningful experiments. In addition, the TI will be redesigned so that it is displayed on its own dedicated interface. This way, the TI becomes larger and thus more manageable. Furthermore, this has the advantage that dependencies between individual tasks can be displayed more easily across packages, thus facilitating coordination between packages. In addition, the tactical map is no longer covered by the TI, which further increases the overview and operability of the cockpit interface.

References

1. Gangl, S., Lettl, B., Schulte, A.: Management of multiple unmanned combat aerial vehicles from a single-seat fighter cockpit in manned-unmanned fighter missions. In: AIAA Infotech@ Aerospace (I@ A) Conference, p. 4899 (2013)
2. Behymer, K., et al.: Initial evaluation of the intelligent multi-uxv planner with adaptive collaborative/control technologies (IMPACT) (2017)
3. Schulte, A., Donath, D., Lange, D.S.: Design patterns for human-cognitive agent teaming. In: Harris, D. (ed.) EPCE 2016. LNCS (LNAI), vol. 9736, pp. 231–243. Springer, Cham (2016). https://doi.org/10.1007/978-3-319-40030-3_24
4. Schmitt, F., Roth, G., Schulte, A.: Design and Evaluation of a Mixed-Initiative Planner for Multi-Vehicle Missions (2017)
5. Heilemann, F., Schmitt, F., Schulte, A.: Mixed-initiative mission planning of multiple UCAVs from aboard a single seat fighter aircraft. In: AIAA Scitech 2019 Forum, p. 2205 (2019)
6. Uhrmann, J., Schulte, A.: Task-based guidance of multiple UAV using cognitive automation. In: COGNITIVE 2011, The Third International Conference on Advanced Cognitive Technologies and Applications, pp. 47–52 (2011)
7. Heilemann, F., Schulte, A.: Interaction concept for mixed-initiative mission planning on multiple delegation levels in multi-UCAV fighter missions. In: Karwowski, W., Ahram, T. (eds.) IHSI 2019. AISC, vol. 903, pp. 699–705. Springer, Cham (2019). https://doi.org/10.1007/978-3-030-11051-2_106
8. Heilemann, F., Schulte, A.: Experimental evaluation of an adaptive planning assistance system in manned unmanned teaming missions. In: Schmorrow, D.D., Fidopiastis, C.M. (eds.) HCII 2020. LNCS (LNAI), vol. 12197, pp. 371–382. Springer, Cham (2020). https://doi.org/10.1007/978-3-030-50439-7_25
9. Fredriksen, P.K.: 26 Interaction in Aerial Warfare: The Role of the Mission Commander in Composite Air Operations (COMAO). In: Interaction: 'Samhandling' Under Risk. Cappelen Damm Akademisk/NOASP (Nordic Open Access Scholarly Publishing) (2018)

Swarms, Teams, or Choirs? Metaphors in Multi-UAV Systems Design

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Abstract. Future Unmanned Aerial Vehicles (UAVs) are projected to fly and operate in swarms. The swarm metaphor makes explicit and implicit mappings regarding system architecture and human interaction to aspects of natural systems, such as bee societies. Compared to the metaphor of a team, swarming agents as individuals are less capable, more expendable, and more limited in terms of communication and coordination. Given their different features and limitations, the two metaphors could be useful in different scenarios. We also discuss a choir metaphor and illustrate how it can give rise to different design concepts. We conclude that designers and engineers should be mindful of the metaphors they use because they influence—and limit—how to think about and design for multi-UAV systems.

Keywords: Drone swarm · Human-swarm interaction · Metaphor

1 Introduction

Swarm robotics is a field dedicated to how relatively simple robotic agents, such as Unmanned Aerial Vehicles (UAVs, or *drones*), can collaborate by mimicking the behaviors of biological systems, such as ant colonies or beehives. In this paper we explore this apparent *swarm metaphor*, compare it to other generative metaphors, and discuss its implications for the design and development of drone swarm systems. Before diving into the nature of swarm behavior, however, we will briefly discuss the fundamental properties and function of metaphor in everyday life and, importantly, in systems design.

Figurative speech (metaphor, metonymy, etc.) is not a mere linguistic curiosity, but an indication of how we think. *Conceptual metaphor* is at the heart of both thought and action in our everyday lives [1–3]. The central mechanism of conceptual metaphor theory is *cross-domain mapping*, which is the process of identifying and establishing links between a *source domain* and a *target domain* that we wish to understand, experience, or explain [1, 2]. For instance, in the LOVE-IS-A-JOURNEY metaphor, the *TRAVELLERS* in the JOURNEY source domain correspond to the *LOVERS* in the LOVE target domain,

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and a journey's *DESTINATION* is metaphorical to the *RELATIONSHIP GOALS* of a romantic relationship [1]. While some mappings between the source and target domains are explicit as in the above examples, others are inferred, or *entailed* [1]. For instance, the LOVE-IS-A-JOURNEY metaphor entails that, because a journey can be exhausting to the point where some rest is needed, the same could be true for love, as in "we're taking a break in our relationship". Additionally, conceptual metaphor typically serves to understand a relatively abstract target domain (e.g. TIME) in terms of a source domain that we can more readily experience (e.g. MOTION), which is also why conceptual metaphors are typically unidirectional in nature [1]. *Primary metaphor* theory attempts to resolve the apparent contradiction of a target domain already having an invariant conceptual structure (or image schema) that dictates how the source domain can be mapped onto it, while simultaneously being in need of "borrowing" the source domain structure due to itself being too abstract [1]. Primary metaphors are "basic" metaphors that are grounded in our direct bodily experience, such as KNOWING-IS-SEEING. Compound (or complex) metaphors involve the conceptual blending of primary metaphors, like THEORIES-ARE-BUILDINGS [1].

Metaphor has long been an important tool for designers, especially in the digital age where new, abstract concepts must be presented in reasonably intuitive ways. A ubiquitous example is the COMPUTERS-ARE-OFFICE-DESKTOPS metaphor through which computer's internal mechanisms (and our conceptual understanding thereof) are structured in terms of "files", "folders", or "waste bins" [4, 5]. In this way, metaphor enables the user's interpretation of digital designs by providing semantic information and physical reference points [5]. Metaphor is also a powerful tool for designers themselves in all stages of the design process: to reframe a design problem to highlight certain elements while concealing others [1, 5], communicate their conceptual design model to others [4], or formulate and test design theories [5]. Furthermore, design metaphors can be either *descriptive* or *prescriptive* in nature. Descriptive metaphors primarily serve to recontextualize a design problem to give the designer a better understanding of it. Prescriptive metaphors cast the design problem in an entirely different light, helping the designer to generate novel design solutions [6]. This second kind of design metaphor is more commonly referred to as *generative metaphors* [3]. These are a special case of "seeing-as" metaphors that enable new ways of viewing the world, which promotes innovation [3]. As an example, Schön [3] describes how, tasked with improving the paint-transferring properties of a paintbrush with synthetic bristles, somebody in a product development team pondered aloud how "a paintbrush is a kind of pump". This prompted the team to think about the spaces in between the bristles as channels for the paint to flow through. When studying how the "channels" of the synthetic brush reacted to the brush being pressed onto the canvas, the team noticed that they bent at a sharper angle than natural bristles. They believed that this restricted the flow of paint and researched different ways to improve this aspect of the synthetic brush until it transferred paint in much the same way as its natural counterpart. This PAINTBRUSHES-ARE-PUMPS metaphor, Schön argues, is generative precisely because it unlocked new ways of thinking about the problem and its possible solutions. Importantly, Schön further argues that there is no *a priori* similarity between paintbrushes and pumps. Instead, the similarities are realized by directly perceiving or experiencing an artifact in a certain context, like holding a brush to apply paint to a canvas [3]. In other words, (generative) metaphors *create* similarities [2].

2 The Swarm Metaphor

To analyze the swarm metaphor, one must first understand the fundamental properties of swarms. The noun "swarm" typically evokes images of a great number of agents, specifically bees, that move in a dense formation. A definition of swarming focuses on how members of a group interact: "Swarming: A collection of autonomous individuals relying on local sensing and reactive behaviors interacting such that a global behavior emerges from the interactions" [7, p. 3]. This essentially describes what insects like ants and bees do. What are the benefits of this behavior that prompt us to want to implement it in multi-UAV systems? It is *decentralized*, meaning that there is no leader, which, together with its *robustness* and *scalability*, contributes to its general *resilience* to change [7]. Moreover, swarming agents' ability to self-organize means that a swarm is flexible, adapting dynamically to changes in the environment. Concerning drones, the intended product (or goal) of all this—the emergent, global level behavior—is that a swarm of simple (i.e. cheap, expendable) agents can perform the same tasks as a single complex (i.e. expensive) agent [7]. In other words, swarms trade efficiency for simplicity.

The MULTI-UAV-SYSTEMS-ARE-SWARMS metaphor, henceforth simply the "swarm metaphor", is a compound metaphor relying on the unification of several primary metaphors. The mappings of the swarm metaphor are presented in Table 1.

Table 1. Selection of role mappings of the swarm metaphor (using bees).

Source: Bee swarm		Target: Multi-UAV system
Bees	→	Drones
Beehive	→	Home base
Beekeeper	→	Drone operator
Touch/Pheromones/Dance (communicate)	→	Short range (local) data links
Foraging for food (survival)	→	Search/retrieve task (mission)
Swarming	→	Coordinating group activity

The *DRONES-AS-BEES* mapping entails that drones and bees share some attributes. Individual bees have limited cognitive capacities but compensate by acting as a collective. This suggests that drones, too, require only enough computational power and sensor quality to function individually while maintaining the ability to collaborate with other drones. This reduces cost. However, adhering too strongly to the metaphor may needlessly limit the capacities of the swarm. Drones, equipped with sophisticated sensors and software systems, have greater potential for intelligent behavior than insects. In short, designers must be careful not to wear the swarm metaphor like a straitjacket. Another inference is that because worker bees essentially sacrifice themselves when attacking and stinging intruders, perhaps drones could have similar abilities, like risking structural damage or battery drain to complete a task. This ties into the idea of individual drones being relatively expendable. From a system design standpoint, the metaphor prompting us to think of drones as bees brings to the fore our existing understanding of how singular bees typically behave and projects these bee qualities onto drones.

Next, the *DRONE-OPERATORS-AS-BEEKEEPERS* mapping entails aspects of control. Beekeepers maintain bee colonies to use them to collect honey from the hive. By the same token, the drone operator assumes a supervisory role, using the drone swarm to accomplish a goal. Furthermore, beekeepers can only indirectly affect the behavior of individual bees or the hive, and the drone operator is also limited to implicit control of the swarm and its member drones, according to the metaphor. Indeed, methods for controlling drone swarms are a prominent topic in human-swarm interaction research.

The *COORDINATION-AS-SWARMING* mapping can be tied into the *BEE-COMMUNICATION-AS-NETWORK-COMMUNICATION* mapping to explain the focus in swarm research on having the drones (or software agents) cluster in swarms by utilizing local sensors and data link networks. An important line of research, but the metaphor risks distracting researchers from exploring other solutions. What if the drone communication network is global to the swarm? Existing on-board communication equipment already has a range of several kilometers, raising questions about the purpose of having drones fly in close formation. A more interesting entailment, which ties back to the question of control, is that bees (like ants) use *stigmergy*—depositing pheromones in the environment—to communicate. This local communication is studied and simulated in swarm research by enabling drones to deploy virtual beacons.

In summary, the swarm metaphor, as a generative metaphor in multi-UAV systems design, is useful in the sense that it promotes simple solutions to tackle complex tasks. However, its simplicity poses different design challenges; the performance outcome of the swarm is inherently probabilistic as there is no way of knowing what any individual drone will do or how its behavior will impact the swarm overall. Designing usable emergent systems, like drone swarms, is notoriously difficult [7]. We will now briefly compare this approach to another generative metaphor: *teams*.

3 The Team Metaphor

In the MULTI-UAV-SYSTEMS-ARE-TEAMS metaphor, or the “team metaphor”, the *DRONES* map onto *TEAM MEMBERS*. They typically have specialized and complementary skillsets to cover different tasks and responsibilities, and drones are entailed to be more capable and autonomous than in the swarm metaphor. This further means that drone team members are typically *not* expendable like their swarm counterparts. In the team metaphor, the role of the *DRONE OPERATOR* maps onto the *MISSION COMMANDER*, who supports and monitors the team, providing information and tasks. From a control standpoint, this is more complex than the *BEEKEEPER* of the swarm as the *MISSION COMMANDER* is in direct communication with the team, enabling direct influence on each member. Regarding communication, while swarm members broadcast basic information to all in their vicinity, team members communicate semantically rich information to specific individuals [7]. The *COORDINATING-GROUP-ACTIVITY* of the multi-UAV target system corresponds to *PLANNING* in the team metaphor, highlighting that teams engage in deliberate, goal-driven activities where all team members have some awareness of the team's mission and task allocations. This is not the case for swarms. A final inference is that teams can have team leaders, meaning that there could be a leader drone coordinating local task allocation and acting as a liaison between the team and the drone operator.

Table 2 juxtaposes swarms and teams, and a comparison suggests that they are suited for different things. No single one of these generative metaphors can adequately facilitate our understanding of what multi-UAV systems can be. Why do bees swarm whereas wolves work as a team? Is one approach superior to the other? In nature, the two systems evolved for different reasons, in entirely different creatures. However, Clough [7, p. 8] observes that "simple animals use simple ways of working with each other", and notes that "swarming things are not smart. If they were, they'd team!" This suggests that the two strategies are not necessarily mutually exclusive in designing autonomous multi-UAV systems. Perhaps the two can be applied in parallel, with focus shifting between them. Or maybe the two metaphors can be unified into a new conceptual blend. This brings us to our final metaphor.

Table 2. Comparison of Swarm and Team properties. Adapted and expanded from [7].

Attribute	Swarm	Team
Temporal	Reactive	Predictive
Composition	Homogenous	Heterogenous
Interrelationships	Simple	Complex
Predictability	Probabilistic	Deterministic
Individual worth	Expendable	Critical
Efficiency	Low	High
Relative cost	Low	High
Controllability	Low	High

4 The Choir Metaphor

Consider the multi-UAV system in terms of a choir or an orchestra [8, 9]. In such a metaphor, *DRONES* map onto *SINGERS*, the *DRONE OPERATOR* becomes the *CHOIR CONDUCTOR*, the *MISSION* is equivalent to the *SONG*, and so on. Like team members, choir singers are highly skilled and have different responsibilities, but they are divided into subgroups singing different harmonies of the song. They must pay close attention to sing in sync with their subgroup as well as the rest of the choir. Naturally, they must know the parts of the song and their role in it. In this metaphor, the individual singer is less critical than in a team, but also less expendable than in a swarm, sitting somewhere in between. While the composer orchestrates the piece and its harmonies, the conductor guides the choir throughout their performance. The conductor sets the tempo for the entire choir and, using gaze, body language, and special signs, communicates with and instructs the entire choir, any of its harmonic subgroups, or even individual singers to pay closer attention or modulate their singing. In a multi-UAV system, the drones could keep a local copy of the mission (like sheet music) in case they lose data connection links with ground control (analogous to forgetting the lyrics).

5 Conclusion

The choir metaphor immediately brings different design ideas and solutions to the forefront than swarm or team metaphors. The point here is not that one of the generated design concepts is *better*, just that they are *different*, but each of them can be *useful* depending on the context of use. The power of metaphors—conceptual and generative alike—is fully realized when we engage with them in a dialogic way. While explicit source-domain role mappings are more immediately intuitive and obvious, the inferred or entailed mappings are usually only revealed upon closer inspection of the metaphor. This back-and-forth between people (in language or in system design) and the metaphor reveals its strengths *and*, perhaps more importantly, its weaknesses. The use of metaphors therefore requires a level of reflective analytical care [2]. The use of generative metaphors in multi-UAV systems design is no different in this regard. We ought to be mindful of, and question, the metaphors we use and consider what assumptions—explicit or inferred—they prompt us to use as basis for our design work.

References

1. Evans, V.: Cognitive Linguistics: A Complete Guide. Edinburgh University Press, Edinburgh (2019)
2. McClintock, D., Ison, R., Armson, R.: Conceptual metaphors: a review with implications for human understandings and systems practice. Cybern. Hum. Knowing **11**, 25–47 (2004)
3. Schön, D.A.: Generative metaphor: a perspective on problem-setting in social policy. In: Ortony, A. (ed.) Metaphor and Thought, pp. 137–163. Cambridge University Press, Cambridge (1993)
4. Neale, D.C., Carroll, J.M.: The role of metaphors in user interface design. In: Helander, M.G., Landauer, T.K., Prabhu, P.V. (eds.) Handbook of Human-Computer Interaction. Elsevier, New York, pp. 441–462 (1997). https://doi.org/10.1016/B978-044481862-1.50086-8
5. Dove, G., Lundqvist, C.E., Halskov, K.: The life cycle of a generative design metaphor. In: Proceedings of the 10th Nordic Conference on Human-Computer Interaction - NordiCHI 2018, pp. 414–425. ACM Press, New York, New York, USA (2018). https://doi.org/10.1145/3240167.3240190
6. Hey, J., Linsey, J., Agogino, A.M., Wood, K.L.: Analogies and metaphors in creative design. Int. J. Eng. Educ. **37**, 283–294 (2008)
7. Clough, B.T.: UAV swarming? So what are those swarms, what are the implications, and how do we handle them? In: AUVSI Unmanned System Conference, Orlando, FL (2002)
8. Boy, G.A.: The Orchestra: a conceptual model for function allocation and scenario-based engineering in multi-agent safety-critical systems. In: Proceedings of the European Conference on Cognitive Ergonomics, VTT, Helsinki, Finland, pp. 187–193 (2009)
9. Boy, G.A.: Orchestrating Human-Centered Design. Springer, London (2013). https://doi.org/10.1007/978-1-4471-4339-0