

The wealth of digital services around us needs organizing, or better “orchestration”. To make applications trustworthy for end users, the “next-generation web” will need special software technologies designed to guide and protect users as they navigate digital spaces.

“Digels”, digital *genius loci* engines to guide and protect users in the “next web”

By TULLIO VARDANEGA and MARC DURANTON

Today, the very notion of “normal” life is largely intertwined with digital services. In many areas of our lives, digital services provide various manners of augmentation, which is both an enormous benefit and a serious threat. This trend – which is very visible to anyone – is only set to increase, as the “next web”¹ transforms the digital sphere, incorporating cyber-physical elements and artificial intelligence to take user experience to a wholly new level of immersion and personalization.

This “next web” vision is an opportunity to join intellectual forces and competences to address the technical challenges involved in making a seamless web environment (a kind of “ubiquitous browsable multidimensional reality”) actually possible. The most significant challenges concern technical complexity, the interoperability of solutions, and the embedding of artificial intelligence (AI) in any computing device connected with it [1]. Other equally important concerns in this endeavour arise in relation to the threats of privacy breaches, exposure to misinformation, polarization and user addiction, to name just a few.

The 2021 HiPEAC Vision article “ ‘Guardian Angels’ to protect and orchestrate cyber life”, argued that it is necessary to create “guardian angels”, personalized digital engines capable of guiding and protecting users in their interactions with digital services. Personalized, loyal and user-centred, these would also be capable of communicating with one another to access more services [1].

Building on this theme, this article presents mark II of the “Guardian Angel” concept: Digel. The Latins used the term “genius loci”, literally “born-in-place”, to designate an ethereal entity that was the “protective spirit of a place”. This notion can be transposed to the web sphere, whose vastness, complexity, and perils call for a loyal, trustworthy virtual entity, fully inhabiting the webspace, to accompany us in our meanderings across it. We call this “Digel”, for “digital genius loci”. While different in many ways, this concept has acknowledged points of contact with the open-source federated personal assistants such as Genie, created by researchers at Stanford University [2].

The Digel will be the heart of the “next web”, a web-powered platform offering composable services. These services will be associated with contracts specifying both functional and non-functional requirements (regarding, for instance, response time, latency, energy), containerized “migratability” to local computing resources, cost of use, etc. Future applications will result from the orchestration and composition of such services.

One of the key functionalities of Digels will be to orchestrate the provision of user-tailored services by coordinated and controlled aggregation of services already present on the platform at large, selected in accord with users’ preferences and requirements, and delivered in as-a-service modality of execution. These orchestrators will also be in charge of managing inbound (security, verification of trust) and outbound (privacy and confidentiality) data, actively protecting the users’ assets. The “programming” of these next-web engines will be done using natural interfaces, such as voice, drawings and schematics, or even by examples –an act, a thing, a discourse that describe the intent –thanks to the interpretation and generalization capabilities of AI.

¹ We do not use the Web 3.0 or Web3 designations of our next web concept, as there are currently differing interpretations of those terms. “Web3” has been taken by blockchain and non-fungible token (NFT) platforms. Web 3.0 as seen by Tim Berners-Lee is a different entity, decentralized, and based on an extra layer above web 2.0, using “pods” to secure private data. For others, Web 3.0 is the “semantic web” that connects knowledge.

Key insights

- Digel engines will operate across the compute continuum from extreme-edge IoT to the cloud. By protecting the digital assets of users, they will ensure a trustworthy interface between the physical world and the cyberspace.
- Digels and multi-layered compositions of them will be the seed of the “next web”, by allowing users to create complex personalized applications by orchestrating the selection, the workflow and the data exchanges between pre-existing services. The resulting orchestrated applications will intertwine the cyber and physical worlds with guarantees of fulfilling functional and non-functional requirements arising from service composition, in a safety- and security-aware manner, for both business and personal use.

- Digels should be user friendly and easy to interact with, allowing even those unfamiliar with today’s computing technology to benefit from digital services.
- Digels will execute orchestration “scripts” automatically generated from requirements expressed by natural interfaces (voice, graphics, gestures, examples, ...).
- It will be possible to embed the compute core of Digels, where their execution behaviour will be programmed, and all of its private data, in resource-scarce devices.
- Digels should be built on top of existing technologies and be interoperable with them.

Key recommendations

- Proof-of-concept developments of Digels, with their orchestration and composition capabilities should be promoted as part of future EU-funded collaborative research-and-innovation programmes.
- Such explorations should promote selective evolution of state-of-the-art web technologies, and integration around specific exploratory scenarios that allow key features to be showcased.

Some background on personal assistants

Once upon a time, there were “personal digital assistants”: hand-held computing devices that mimicked the abilities of personal computers (PCs), only on a small scale, with application functions mostly confined to office suites and small applications. The advent of smartphones replaced these devices entirely, while helping transform the very localized notion of an office to a cloud-enabled “anywhere” hosting and computing platform, powered by Web 2.0 network protocols.

Then came AI-powered digital assistants, which eschewed traditional forms of human-to-computer interaction in favour of voice commands, conversational bots and contextual helpers. The next frontier of these digital assistants points to edge-based (as opposed to cloud-centred), privacy- and security-aware personalized digital engines. These digital engines would be programmed (rather than just commanded) by natural interfaces into orchestrated compositions of web services deployed in an everything-as-a-service delivery mode, where sensitive data are kept local and computation moves as needed according to a factors such as opportunity, convenience, privacy, energy, latency and cost.

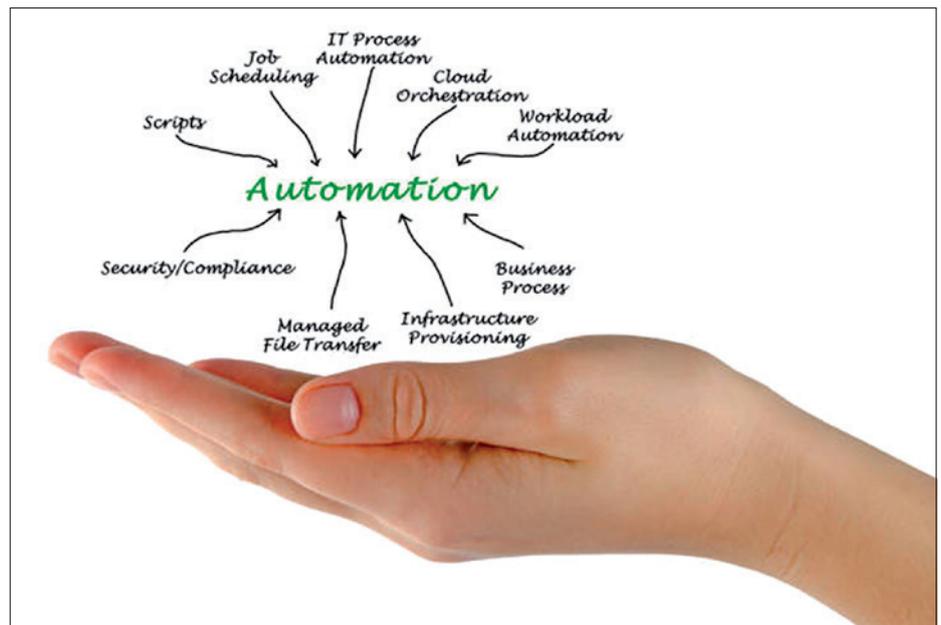


Figure 1: a pictorial evocation of humanistic orchestration. Source: Dmitry on Adobe Stock

Bird’s eye reconnaissance of the technical landscape

The notion of the “continuum of computing” reflects the observation that edge, fog and cloud computing platforms are being pulled together into what is bound to become a seamless execution environment. One of the factors behind this trend is the massive and unabating growth of value-added applications for

mobile, handheld, wearable and unattended devices, in addition to traditional server-side applications. This explosion in complexity calls for self-managed workflow-based orchestration capabilities to meet emerging user requirements, whether personal or industrial, that cannot be met by any one component alone.

Interestingly, all those services effectively run on one and the same base

programmable interface, the web, which makes them ubiquitously accessible, intrinsically interoperable and technologically neutral. This programmable platform will be an evolution of the web 2.0 space, more aware of privacy, security, latency, energy, spatial locality, via assume-guarantee interface specifications which will allow Digel engines to apply service orchestration and composition on them.

These intelligent orchestrators would be distinguished by user-centred features, including:

- The ability for the user to instantaneously build their own service aggregator, which knows their preferences and profiles. This service aggregator would be capable of orchestrating services and information available on the web to do the user’s bidding, with the additional ability to change service provider dynamically as the need or opportunity arises.
- The traits of a personalized recommendation engine truly loyal to its user, capable of fetching and selecting information items according to the user’s personal preferences, without being deceived or deflected by provider-side solicitations.
- The ability to use correlation with trusted sources and AI to assess the trustworthiness and authenticity of all news and information items proposed to the user.
- The ability to have the user’s digital exchange with others, whether humans or bots, filtered so as to prevent the inadvertent sharing of information that the user does not positively intend to share. As part of that, the ability to use strictly private past-behaviour analysis to help the user break away from information silos



Figure 2: A pictorial representation of the Digel, generated by Stable Diffusion [4]



Figure 3: a scene of the HiPEAC Comic Book [3], which evoked the Guardian Angel concept as it was described in [1].

and filter bubbles, and to prompt users to update their preferences accordingly.

As we noted in [1], a number of state-of-the-art or in-development technologies may be regarded as the base to what will be needed to create Digel engines for real. For obvious reasons of practicality these orchestrating engines should be built on top of existing technologies and be interoperable with them. A non-exhaustive list of technology axes that need to be developed includes:

- The as-a-service delivery mode.
- Use of the highest levels of the internet protocol stack (HTTP/3).
- AI-assisted service provisioning, migration, and orchestration based on multi-objective optimization (e.g. performance, privacy, security, energy, emissions).
- A lightweight trusted computing base (similar to the mechanics behind modern web browsers), written in memory-safe programming language and verified by verification tools before compilation and deployment.

- Execution by lightweight containerized sandboxed interpretation, possibly in just-in-time mode, such as that used in WebAssembly [5] technology.
- Dynamic web directories for specification-based, resource-aware service discovery, provisioning, migration, and orchestration across the compute continuum.
- Dynamic programmatic orchestration of the services in a trusted and secure way, for example by cloud-native application programming interface (API)-integration languages like Ballerina [6].
- A human-friendly, natural way to program the orchestrator, for example based on speech-to-code transformation presumably powered by AI solutions.
- Human-friendly interface for non-specialists, able to assess the user’s status and adapt to their reaction.
- Recommenders that can be run locally, with better security and control of their results.
- Digel engines should be able to collaborate in a trusted way to carry out aggre-

gations than cannot be achieved by one Digel alone, enlarging the scope of their capabilities.

- Digel engines should be capable of operating individually or collaboratively to detect fake or untrusted data and to assess the trustworthiness of the data accessed.
- Privacy- and security-preserving sharing and offloading of mobile data and computations to potentially untrusted hosts, using combination of detective deep-learning techniques, federated computation models, and homomorphic encryption.

Conclusion

As we concluded in [1], internet-of-things (IoT) devices, edge and deep-edge devices, and smart assistants are at the interface between the real and the cyber worlds. However, owing to the increasing inherent complexity of the cyber world, using it efficiently and safely is becoming more and more challenging, both for industrial and personal users. From the user’s point of view, a single trustable entry point simplifying and supporting interactions with digital services will be required. We propose the “digital genius loci”, or Digel, as this point of entry.

Our vision for the “next web” is a platform which intertwines the cyber and physical worlds for both industrial and personal use, overcoming the fragmentation of vertically oriented closed systems, the heterogeneity and the lack of interoperability. It will increase scalability in a dynamic environment where systems should self-configure, self-manage and be plug-and-play, while also coping with security and privacy of personal and corporate data. Orchestrators for our proposed Digels will contribute to the interoperability and trustworthiness of this vision of the “next web”.

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