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A formal framework for linking multidisciplinary multiscale knowledge.
A case study on rodent population dynamics and management

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Abstract

We have explored and tried to formalize the knowledge and approaches of a multidisciplinary team of scientists working on diverse aspects of rodent biology. Within this research field, the knowledge provided by each disciplinary viewpoint appears as a legitimate part of the concrete observation. Despite the difficulty of considering multiscale knowledge, attempting to integrate the existing disciplinary approaches could contribute to a possible overall picture of a unique natural system.

A methodological framework has been developed for expressing the relationships between these diverse items of knowledge in a formal manner. We have established a set of ontologies of the research field from various types of contributions from scientists working in the area. This has led to the formal specification of a simulation platform. We described five contrasted case studies using this platform. Combining viewpoints from different disciplines appears as a promising approach to tackle the complexity of a given research field.

Context and objectives

This work is based on the studies carried out by a multidisciplinary research team investigating the biology of rodent populations. The scientific approaches of the team are extending from the gene to the ecosystem, with temporal scales extended from the minute (*e.g.*, physiology) to billions of years (*e.g.*, phylogeny). The focus on particular phenomena provided by each study and discipline is specific and generally, by definition, unique. Each scientist thus owns a unique questions set (Figure 1) and various approaches are used, providing different pieces of knowledge.

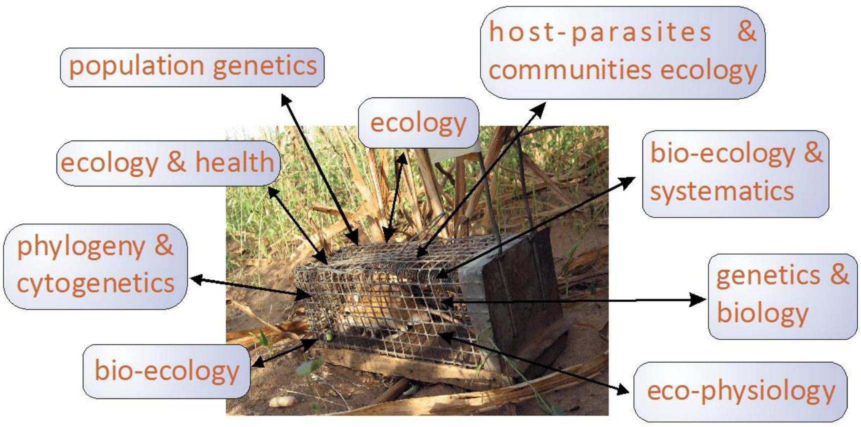

Figure 1. Rodent (Taterillus sp.) trapped in the field in Mali (West Africa). Observations made in the field raise multiple questions (Singleton et al., 1999, Wolff et al., 2007): contributions from scientists working in many disciplines are needed to understand all aspects of the natural phenomenon[2].

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[2] As an illustration, 35 disciplines were identified by scientists working in the field for the description of a small set of 25 single items of information relating to rodent biology: agronomy, anatomy, biogeography, biology, biometrics, community ecology, conservation biology, conservation genetics, cytogenetics, cytotaxonomy, ecology, ecophysiology,

Each single approach *(i)* represents a legitimate view, *(ii)* may be applied simultaneously and *(iii)* contributes to an overall picture of a unique natural system. Making connections between knowledge may provide alternative interpretations of the status, role and fate of these rodent populations. We have explored the multidisciplinary approach of this group, with the aim of developing a formal solution for the mutual combination of these diverse items of knowledge.

Method

We focused on connection of items across the various disciplinary fields. For this purpose, four typologies have been successively elaborated which led to the design of a multipurpose modelling platform. The first was based on thorough individual interviews conducted with most of the scientists of the group, concerning their knowledge and activity using a formalized protocol (documentation, interaction/consultation, elicitation, reification, articulation, formalization). A textual analysis of the content of these interviews was then carried out to allow generation of a list of common keywords (Fig.2). Stepwise classification of this list into meta-keys led to the establishment of a first ontology for the research domain investigated.

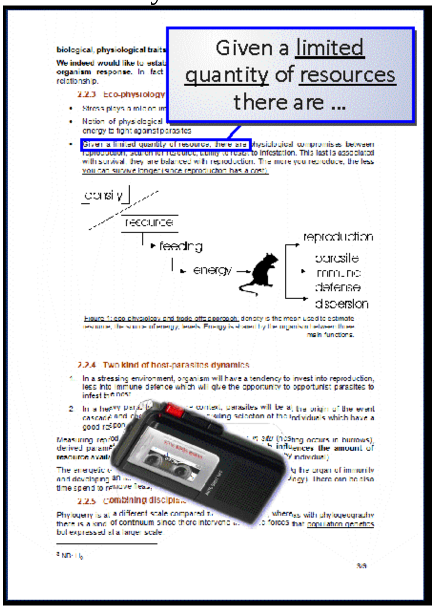

Figure 2 - transcription of a scientist interview about its research domain and question sets. Significant keywords are thereafter individualized and classified.

The second ontology originated from a dedicated keyword-based information centre in which scientists from whatever discipline could propose single information items about their research. Each information item has been formatted into several fields within a single database. A stepwise classification permitted to incrementally position corresponding keywords within meta-keys defined on demand (see example Figure 3, left panel). This produced a classification built step-by-step and transcribed into an hyperlink network of keys allowing to connect the diverse information set. Single items of information provided by any member of the group were incrementally bound into a network of keys. This gave rise to an ontology in the form of a second set of meta-keys used to express knowledge.

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epidemiology, evolutionary systematics, genetics, immunogenetics, integrative taxonomy, molecular biology, molecular epidemiology, molecular phylogeny, morphology, morphometrics, morphometry, multidisciplinary studies, paleogenetics, phylogeny, phylogeography, population biology, population genetics, population genomics, population management, systematics, taxidermy, taxonomy.

Figure 3 'Centre d'Informations (CI)' web page. Right panel: structure of a single information item proposed by a scientist. Left panel: example of the keywords specifically gathered in the 'bio-process-mechanism' meta-key (see http://simmasto.org/CI.htm).

The two first ontologies have been elaborated using two distinct ways of interaction with scientists. This led to elaborate a third synthetic one. This latter then served as a starting point for the development of a fourth one used for designing the architecture of a modelling platform dedicated to a stepwise integration of the various approaches and scales used to study rodent populations. Using this platform, contrasted concrete use cases have been formalized in collaboration with the thematic scientists to both *(i)* incrementally enrich the platform and *(ii)* test its robustness.r

Results

The two first ontologies (not figured) have many points in common and could effectively be combined into the single, synthetic ontology. Given some adaptation, most of the resulting classification could be then transcribed and contribute to the design of the targeted modeling platform (Table 1).

Table 1 Synthesis of the transdisciplinary features emerging from a synthetic typology (b) and leading to the formal specification of a model (d). The synthetic typology is a combination of the classifications built from *(i)* a dedicated information system, *(ii)* interviews with scientists (see 'Method').

a) Example keywords	b) Synthetic ontology	c) Domain type	d) Package in the model
epidemiology, taxonomy, ecophysiology, ...	Discipline	research question and point of view	protocol
genome and population evolution, host-parasite interaction, population and natural landscape management, rodent community	Research field		protocol
arenavirus, Cricetides, rodents, ...	Biological item	characterization of the subject	thing (NDS*)
estivation, regulation, species adaptation, ...	Bio-ecological process /		thing (NDS)
aridity, agriculture, dry season, ...	Phenomenon		data input
biotope, local scale, equilibrium, ...	Concept		protocol
water, chemical product, irrigated plot, ...	Concrete		thing
Africa - South America, Sudano-sahelian eco-region, un-localized, ...	Location		ground system
Habitat, village, area, continent, forest fragment, island, km2, ..	Spatial scale / space describer		thing (soil)
1903-2007, 2003, a-temporal, geological	Temporal scale / time		time passing
local, ecological, intra-individual, micro-evolutionary, spatio-temporal, ...	Functional scale		
abundance, parasite load, evolution rate, allele frequency, specific richness, karyotype structure, ...	Measure or indicator	knowledge acquisition	epiphyte system
reference list, biological indicator, karyotype, ...	Tool		protocol & epiphyte system
classification, survey, training, ...	Method		protocol

* NDS: Nearly decomposable system (Simon, 1962); term used as a proxy for complex systems organized into a hierarchy
** Epiphyte system: set of observers collecting data on the modelled world and computing indicators

The resulting modelling platform is of the multi-agent kind (object-oriented approach) relating *(i)* space and ground, *(ii)* objects and concrete 'things', including rodents, DNA, roads, trucks or humans, *(iii)* observers providing data about the world modelled and *(iv)* formalized protocols for each specific use case.
Five case studies have been formalized with this platform. Each model was developed in collaboration with the scientists involved in each case study. Various fields have thus been explored and formalized, from the laboratory cage to geographical areas and from crosses between genotypes to fossorial behaviour (Figure 4).

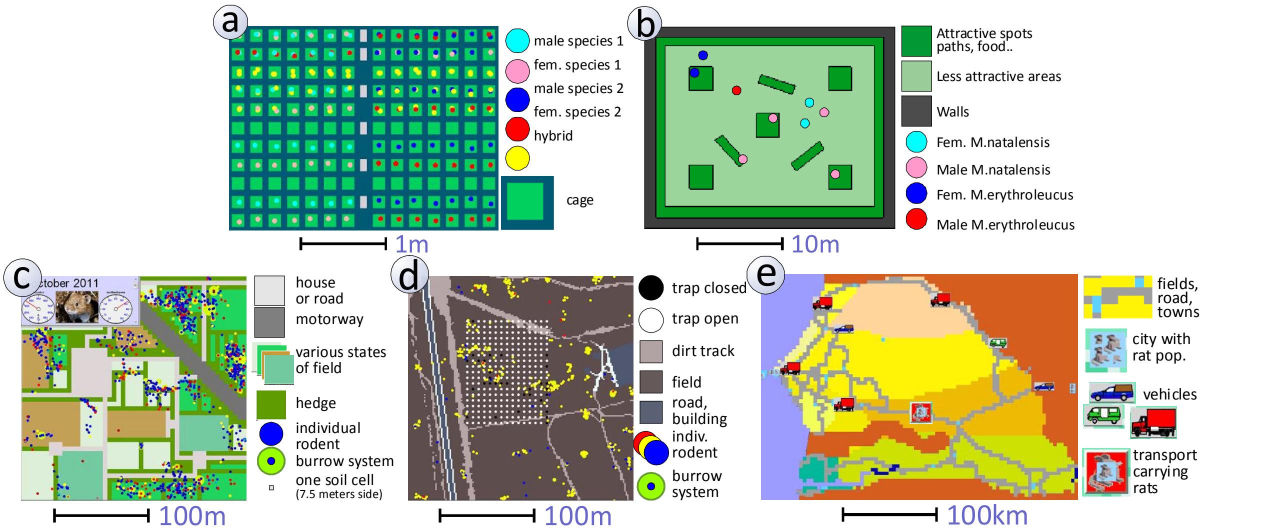

Figure 4 Five use cases embedded in the model proposed. (a) cage and (b) enclosure experiments on sibling species hybridization, (c) vole population evolving within an agricultural landscape, (d) mark-recapture experiment in an African reserve, (e) epidemiology and transportation of black rat by commercial vehicles in Senegal (West Africa).

The platform is developed from a common ontology to ensure that it is robust. Indeed, this approach provided insights into the connections between items of knowledge originating from different sources. The five case studies each enriched and benefited from the mechanisms and components involved in the simulation. This led for example to the stepwise addition of genes, genome, microsatellites, meiosis, fecundation, social behaviour, various types of movements (graphs, deliberate, exploration, stepwise, continuous), protocols, observation, formalisms, data, presentation, ... in the global platform.

Conclusion

The platform proved efficient to share concepts and procedures between very contrasted use cases. The chained combination of several approaches (interviews, ontologies, information centre, simulation platform) constitute a step towards the establishment of a robust knowledge centre for the field concerned. Particularly, using a common ontology provides robustness for forthcoming use cases. However, combining different spatial and temporal scales still could not be achieved.

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