# Computational Synthesis and Creative Systems

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Creativity has become the motto of the modern world: everyone, every institution, and every company is exhorted to create, to innovate, to think out of the box. This calls for the design of a new class of technology, aimed at assisting humans in tasks that are deemed creative.

Developing a machine capable of synthesizing completely novel instances from a certain domain of interest is a formidable challenge for computer science, with potentially ground-breaking applications in fields such as biotechnology, design, and art. Creativity and originality are major requirements, as is the ability to interact with humans in a virtuous loop of recommendation and feedback. The problem calls for an interdisciplinary perspective, combining fields such as machine learning, artificial intelligence, engineering, design, and experimental psychology. Related questions and challenges include the design of systems that effectively explore large instance spaces; evaluating automatic generation systems, notably in creative domains; designing systems that foster creativity in humans; formalizing (aspects of) the notions of creativity and originality; designing productive collaboration scenarios between humans and machines for creative tasks; and understanding the dynamics of creative collective systems.

This book series intends to publish monographs, textbooks and edited books with a strong technical content, and focuses on approaches to computational synthesis that contribute not only to specific problem areas, but more generally introduce new problems, new data, or new well-defined challenges to computer science.

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# Concept Invention

## Foundations, Implementation, Social Aspects and Applications

Springer

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# Foreword

Almost two and a half decades have passed since the birth of the cognitive theory today known as 'conceptual blending' in 1993. In these 24 years, a lot has happened and much has been achieved concerning both theoretical development and empirical evaluation of conceptual blending. As of 2017, the core postulates of the theory are widely accepted, and its manifestations are studied across different disciplines from linguistics to cognitive psychology to computer science and artificial intelligence (and many more). But instead of focusing on a historical perspective on conceptual blending, we want to look at the *status quo* and into the future of the theory and its applications—and more specifically at its role and use in (computational cognitive models of) concept invention.

Roughly speaking, the word 'invention' usually describes a unique or previously unseen—i.e., novel—artifact, idea, or procedure, with examples ranging from musical compositions to technological devices to political theories. Concept invention, thus, is the mental process of creating novel concepts, which again can have many and highly diverse particular manifestations: mathematical theories, mythological creatures, or musical idioms, to name just a few. This capability to bring forth new concepts is often seen as a sign of creativity on the side of the producer, and has been investigated by psychologists, linguists, and cognitive scientists alike. Of course, these studies have also closely been followed by researchers in artificial intelligence, who in turn attempt to build computational models of this human mental faculty—first, to progress closer towards the (re)creation of cognition and intelligence with computational means, and second, to locate applications in support software for creative industries. Conceptual blending as a theoretical framework and as an empirically observable phenomenon is playing a key role in many of these efforts: it suggests a plausible mechanism combining previously independent concepts into—in the interesting cases—novel joint ones.

This also is the context in which the EU-FP7 Concept Invention Theory project (COINVENT), underlying the work reported in this book, is to be seen. Building upon previous efforts by some of the authors of different chapters, as well as by many other renowned researchers, COINVENT aimed to draw together several different lines of work in an attempt to provide conceptual blending-based concept invention with a solid theoretical grounding through a detailed formal model of the underlying processes, together with a worked-out implementation of a system performing blending in two quite distinct application domains, namely theory blending in mathematics and the blending of harmonies in music. As can be seen from the results described in the individual chapters, these goals have been met; and in doing so, a widely visible proof of concept for the power and applicability of conceptual blending as theory and corresponding mechanism for concept invention has been given.

Of course, as is often the case with research projects, much is left to be done: the models and methods have to be applied to further domains, the mechanisms and implementations have to be refined and brought to maturation, and the functionalities have to be further developed, put to use in actual application systems, and rolled out to a general audience. Still, these are by no means shortcomings of the project. To the contrary, these points constitute great opportunities: by showing that conceptual blending can serve as basis for a formally well-founded and implementable model of concept invention, a door has been opened and the way has been cleared for many ambitious follow-up projects. What are the prospects for:

- software frameworks performing blending-based concept invention across domains?
- implementations combining different representations within a perceptual domain, blending speech with music, or text with images?
- multi-modal systems generating novel concepts across different sensory modalities, combining vision, touch, audition, and taste?
- programs co-creatively interacting with designers and artists during the different stages of ideation in the creation process?
- software supporting human agents in developing our own creative abilities and training our imagination?

The range of possibilities seems almost unlimited. Endeavors to answer these questions will lead to insights into computational models of conceptual blending and concept invention, and into the corresponding human faculties and cognitive theory.

We are excited to see these lines of research grow and prosper. We look forward to the advancement of our understanding and use of conceptual blending-based concept invention in the years to come.

Cleveland, Ohio, USA in March 2017 *Mark Turner*
Bremen, Germany in March 2017 *Tarek R. Besold*
Bozen-Bolzano, Italy in March 2017 *Roberto Confalonieri*

# Preface

This book, *Concept Invention: Foundations, Implementation, Social Aspects and Applications*, introduces a computationally feasible, cognitively-inspired formal model of concept invention, drawing on Fauconnier and Turner's theory of conceptual blending—a fundamental cognitive operation underlying much of everyday thought and language, and Goguen's Unified Concept Theory—a computational characterisation of conceptual blending using category theory. It also presents the cognitive and social aspects of concept invention. It describes concrete implementations and applications in the fields of musical and mathematical creativity, and further discusses the evaluation of creative systems.

The book contains ten chapters edited by leading researchers in formal systems, cognitive science, artificial intelligence, computational creativity, mathematical reasoning and cognitive musicology, who contributed to advancing the state-of-the-art of conceptual blending in the European research project Concept Invention Theory (COINVENT). The book presents the results developed, the lesson learned and the perspectives drawn within the COINVENT project in such a way that the reader can get a deep understanding of conceptual blending from the formal, social, cognitive, and applied points of view.

Many excellent books that explore how creativity can be enacted using conceptual blending, and that look at creativity in general, already exist. We can refer to titles such as *Creativity and Artificial Intelligence: A Conceptual Blending Approach* (edited by F. Pereira, Mouton de Gruyter, 2007), and *Computers and Creativity* (edited by J. McCormack and M. d'Inverno, Springer, 2012), just to mention a few of them. This book differentiates itself from other books on creativity and conceptual bending because it elaborates on a knowledge-representation independent formalism which makes it more general and more widely applicable; moreover, it describes cognitive models that relate to conceptual blending such as image schemas and analogical reasoning, and provides examples of application in the domains of mathematics and music. Furthermore, it examines and provides insights on the evaluation of computational creative systems, a widely recognised area of research in machine-enhanced creativity by itself. *Concept Invention* will appeal to any reader interested in how conceptual blending can be precisely characterised and implemented for the development of creative computational systems.

## Summary of the contributions

The book is organised in four parts. Part I introduces the mathematical and computational foundations of concept invention. Part II discusses its cognitive and social aspects. Part III describes concrete implementations and applications of concept invention in mathematical discovery and music harmonisation. Finally, Part IV constitutes an epilogue on the topic of evaluating computational concept invention and, generally, computational creativity systems.

The first three chapters in Part I are devoted both to the theoretical and computational foundations of concept invention. The concrete implementations described in Part III build on these foundations.

Chapter 1 by Félix Bou, Enric Plaza and Marco Schorlemmer provides a deep theoretical analysis of Goguen's Unified Concept Theory (UCT) for conceptual blending. Starting from this analysis, the authors outline a strategy for concept invention that extends UCT with amalgams, a knowledge transfer method proposed in case-based reasoning. In this chapter, the notion of amalgams is generalised and related to the notion of colimit in category theory, making amalgams a computationally feasible concept that form the basis for many of the subsequent chapters.

Chapter 2, by Roberto Confalonieri, Enric Plaza and Marco Schorlemmer, presents a concept invention process supporting the development of creative applications. This process considers two dimensions, origin and destination, in addition to the blending operation itself. These dimensions are typically not considered in the theory of conceptual blending, nor in existing computational frameworks and implementations. On the one hand, origin describes where the creation starts, and is concerned with how the input concepts to be blended are created. Origin is enacted through a Rich Background—intended as a finite but complex, diverse, and heterogenous set of concepts—from which input concepts are discovered according to the user demands. Whilst origin encompasses the discovery and construction of input spaces, the destination dimension is related to blend evaluation. Blend evaluation is conceived as an argument-based decision making framework in which an artificial agent creates arguments in favor or against a blend by taking values and audiences into account. The Rich Background also provides the means to evaluate newly-created concepts through the notion of conceptual coherence, for which the authors give an account in description logic.

The workflow of a system that facilitates ontology-based blending is presented in the last chapter of Part I (Chapter 3), by Mihai Codescu, Fabian Neuhaus, Till Mossakowski, Oliver Kutz and Danny de Jesús Gómez-Ramírez. Given two input ontologies, the workflow creates and evaluates several blended ontologies. To ensure that all generated blends are consistent, the workflow includes a stage where conflicts within concept elements are identified and resolved by generalising some axioms in the input ontologies. This workflow is enacted using the Distributed Ontology, Model and Specification Language (DOL), an international ontology interoperability standard. DOL provides a unified metalanguage for employing an open-ended number of formal logics, such as CASL, and ontologies, via the Ontology Web Language (OWL).

The theory of conceptual blending, and of creativity it general, is related to theories of human cognition. Part II discusses some cognitive and social aspects of concept invention through three chapters that focus on image schemas, the relationship between conceptual blending and analogical reasoning and the social aspects in the invention of mathematical and musical concepts. These chapters help put the computational theories of conceptual blending on a cognitively realistic basis.

Chapter 4 by Maria M. Hedblom, Oliver Kutz and Fabian Neuhaus focuses on image schemas that are, according to cognitive linguistics, fundamental patterns of cognition learned by humans in early infancy. The utilisation of image schemas presented in this chapter incorporates the identification of the common abstract key-element of two input spaces, expressed as an image schema, and the formulation of the generic space based on that. Since image schemas are conceptual building blocks, they appear to be essential to the meaning of concepts and, therefore, they are expected to minimise the number of non-sense blends when applied to conceptual blending processes.

Tarek R. Besold in Chapter 5 outlines a perspective on conceptual blending from the point of view of the cognitive mechanism of analogy-making. In this study, the generalisation of the input spaces that lead to the generic space is analysed under the prism of analogy, where the common elements of the inputs are retrieved as meaningful similarities that are extracted through analogical reasoning. This chapter shows how analogy, amalgams, and conceptual blending are related. The explicit availability of similarities between the input concepts—obtained by analogy using the Heuristic-Driven Theory Projection (HDTP) engine—to an amalgam benefits the overall blending process, since the basic structure introduced by the analogy process is maintained in the creation of new concepts.

Some social aspects of creativity are surveyed in Chapter 6, by Joseph Corneli, Alison Pease and Danae Stefanou. This chapter also gives a succint overview of a formal, computationally feasible model that can describe real-world, social creativity. The chapter surveys approaches to understanding mathematical dialogues. Several example dialogues are marked up with tags that describe the flow of conversation. These tags enable the computational analysis of the exchange of ideas that aim at solving specific problems and, for example, the specification of a protocol that formalises Lakatos's theory of dialogical creativity.

Part III presents the concept invention system, which was developed based on the theoretical background presented in Part I, and two application domains. Chapter 7 by Roberto Confalonieri, Tarek Besold, Mihai Codescu and Manfred Eppe describes COBBLE—a creative, flexible and modular computational prototype that materialises conceptual blending in a generative way—and its enabling technologies. COBBLE makes use of technologies based on notions from the fields of ontologies, analogical reasoning, logic programming, and formal methods. The system allows a user to select input spaces and different techniques for generalisation, outputting the resulting blends as colimits of algebraic specifications. The input spaces are modelled using DOL (described in Chapter 3) that allows for the formulation of blending diagrams encoded in the CASL and OWL languages.

Chapter 8 by Danny de Jesús Gómez-Ramírez and Alan Smaill discusses and shows, with practical examples, the role that conceptual blending plays in the development of new mathematical concepts. This is demonstrated with the reconstruction of existing abstract mathematical theories, e.g., Commutative Algebra, Number Theory, fields and Galois Theory, and also the extension to new equivalences that characterise the notion of Dedekind domain.

The application of concept invention through conceptual blending in harmony is presented in Chapter 9, by Maximos Kaliakatsos-Papakostas, Asterios Zacharakis and Emilios Cambouropoulos. This chapter presents several aspects of the CHAMELEON melodic harmonisation assistant, which allows a user to provide a melody as input, and select two input harmonic spaces learned from data; then CHAMELEON blends the selected spaces, generating a new harmonic style, and harmonises the input melody. The blending module of this system is based on the blending algorithms used in COBBLE, here applied on the level of chord transitions. The new harmonic styles that are invented are judged as new styles that either encompass mixed characteristics of the input spaces, or entirely new elements. Additionally, pilot studies indicate that when composers use CHAMELEON they have a palette of many diverse automatically composed harmonies from which they can draw ideas, a process that potentially enhances their creativity—even though additional formal studies need to be carried out in order to firmly validate this claim.

Part IV is an epilogue that includes Chapter 10, which provides an in depth discussion on the evaluation of computational creativity.

This book presents a wide spectrum of studies that focus on computational concept invention through conceptual blending. Therefore, we hope that this book will constitute a valuable tool for the reader who is interested in the theoretical and computational foundations of concept invention, the cognitive aspects behind and around it, the implementation of a creative system that exhibits creative behaviour, and how such a system can be evaluated.

Bozen-Bolzano, Italy in March 2017 *Roberto Confalonieri*
Thessaloniki, Greece in March 2017 *Maximos Kaliakatsos-Papakostas*

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# Contents

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