

CARICATURAL REASONING

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EXTENDED ABSTRACT

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A striking feature when considering physical phenomena, is our ability to overcome the complexity of their analysis. Capturing and Reproducing such an ability requires going beyond mathematics for physics however sophisticated they may be. A theory of human reasoning about physical phenomena must explicitly embed elements of a methodology to cope with this complexity. The necessity to boost today's qualitative reasoning methodology has become crucial. In this perspective we introduce here caricatural reasoning which is meant to be on top of a simulator, and to control a qualitative reasoning process. It tends to break the complexity of the analysis of dynamical process. It does so by transforming complex universe extracting extreme pictures of it: it's caricatures. Caricatural reasoning first generates extreme world to feed properly a classical simulator. Then it combines the response of the simulator and provides as a result a global picture of the behavior of the system. We explain here how caricatural reasoning can be integrated in a qualitative reasoning process, and outline how the generation and combination of caricatures can be performed.

1 INTRODUCTION

Reasoning about physical phenomena requires much more than the knowledge of physical principles. It also requires much more than mathematics for physics. It is a whole theory of human reasoning about physical phenomena which has to be captured and reproduced. Qualitative Physics has been highlighting this issue and basic foundations and extensions have been already provided (See, 5, 6).

Nevertheless a striking phenomenon we are confronted to, today, is the gap between the necessity to handle complex phenomena, and the limitations of current techniques. We believe that this difficulty is not due to the methodology that have been developed. The complexity of reasoning about physical is one we are all confronted to: humans as well as machine. What we have to embed is some of that skill that makes the specificity of our reasoning about physics. Our concern, here is to capture some of this art that enables us to be efficient in our reasoning about physical phenomena.

Previously we had investigated Order of Magnitude Reasoning as such an ability. The formalism introduced for Order of magnitude reasoning tried to benefit from a traditional way of reasoning about physical quantities. This formalism has two key feature that we should recall:

Firstly by introducing a calculus on infinitesimal number, it introduced a way to reason about *extremes*.

Secondly it imposed a structure in the Quantity Space that broke "interactions" among quantities. This "near decomposition" reduced the complexity resulting from a flat and uniformed "real" line representation and calculus for physical quantities.

Extending order of magnitude reasoning to explicitly attempt to break the complexity in the analysis of dynamics is tempting. But straightforward extensions ends up increasing the difficulty of the reasoning process and introduces even more ambiguities. To break the complexity of the analysis of dynamical process, we draw once again inspiration from traditional way of reasoning. The Generalization were are investigating attempts to keep the two basic properties just mentioned concerning order of magnitude reasoning: Namely the ability to reason about extreme worlds, and nearly decompose the universe. This

time beyond quantities, what has to be structured are interactions among individuals. *Caricatures are these extreme and exaggerated pictures*

This papers describes how caricatural reasoning can be done. 1) A motivating example is given to point out the kind of traditional reasoning we are trying to capture. 2) The architecture is outlined by explaining how caricatural reasoning is meant to feeds and control simulation process 3) explains the generation of caricatures which are to be given to the simulators. 4) describes how to combine caricatures which set back together the the result of simulating the behavior of basic extreme worlds.

II A Motivating Example

Consider the following universe U consisting of the Earth, the Sun, the Moon and a space_lab going from the earth to the moon.

Individuals := {*Earth, Sun, Moon, Space_lab*} .



Figure1 : Earth Sun Moon

A picture of the behavior of this system can be roughly given as follows:

"The Earth and the Moon turns around the Sun and the Moon turns around the Earth. To voyage from the earth to Moon the space_lab will have to get out of the attraction of the earth, and then to voyage between the planets and finally become under the attraction of the moon and land.

Deriving such information from physical principles, cannot be done with a brute force process. Even with powerful mathematical tools this cannot

be done (analytically) It is a well known theorem of physics that asserts the inability to solve such a dynamic system: the N body problem. If a problem solver is given this universe and ask to respond how it will behave, it will fail. The problem solver is not to incriminate, since there is no way to solve this problem.

The skill necessary to handle such a case relies on an ability to generate a structure among interactions; more precisely breaking the symmetry of the problem and decomposing it by ordering interactions and therefore impose a structure among them|

This is why an "intelligent" part of the analysis of the behavior of the individuals of this universe is upstream: *it consist of feeding up correctly the simulator* Intuitively this can be understood for instance by assuming that the Sun will remain unaffected by other individuals; that the motion of the Earth will be governed only by the presence of the Sun and that the Moon will be affected only by the earth, as a satellite. Voyager, the space-lab, will start to be only influenced by the Earth then become "isolated", and finally enter the sphere of attraction of the Moon.

It is a methodology for achieving such reasoning that we attempt to define here.

III PERFORMING CARICATURAL REASONING

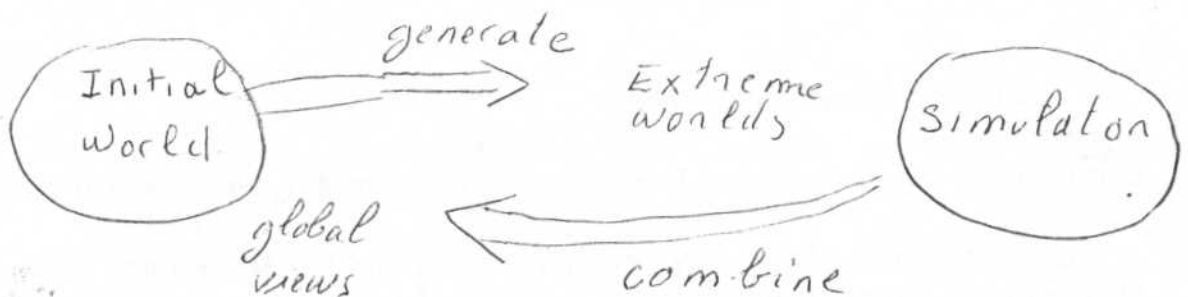


Figure2 Basic Caricatural Reasoning Architecture

Lets us explain how caricatural reasoning works: A basic caricatural reasoner takes as *input* a universe made of individuals and process or interactions governing the dynamic of this universe.

The task of caricatural reasoning is to transform this universe and generates extreme universes. It feeds the simulator successively with these new universe. It takes the result of the different simulation and combines them to provide a global views of the dynamic of the universe.

As in order of magnitude reasoning where primitives and rules where introduced, here we have to capture by introducing new primitives and rules an ability to structure physical interactions. This is done by performing what corresponds intuitively to the idea of *overemphasizing* The consequence of overemphasizing is to select and focusing on particular individuals, while temporarily ignoring other ones. The two main task of caricatural reasoning:a

- *The Generation of caricatures*
- *The Combination of caricatures*

IV GENERATING CARICATURES

The generator of caricatures transform an initial universe U in a caricatural one $C(U)$ The task is to break the complexity, break the generality, and the result is a decomposition of the universe.

This generation process is essentially guided by three analysis:

- It is governed by an analysis of the different *individuals* and a decomposition of these individuals in classes is performed
- A hierarchical decomposition of the *interactions* or process among these classes of individuals is performed by putting explicitly the emphasis on some criteria affecting the importance of the different interactions.
- It is *goal oriented* , for a given universe caricatures changes according to the problem to solve.

The generation of caricatures is time dependant these caricatures are to be change with time. But within a simple caricature the structure of interactions is fixed.

IVa) DECOMPOSING INDIVIDUALS IN DIFFERENT CLASSES

One of way to generate of caricatures, is to group individuals among classes, (in the same way that order of magnitude reasoning merges quantities in equivalence classes according to their order of magnitude).

This can be done by grouping individuals that can be considered a behaving as a class with respect to all others. For instance as far as the basic example is concerned, the distance criteria (which affects gravitational interaction) the Moon and the Earth can be temporarily merged into one class. (Overemphasizing the distance criteria).

Initially the following relations are given as holding uniformly with respect to time.

$$d(\text{Sun, Earth}) > d(\text{Moon, Earth})$$

$$d(\text{Sun, Moon}) > d(\text{Moon, Earth})$$

Overemphasizing this relation in the attempt to structure the physical phenomena by defining subsystem will lead to:

$$d(\text{S,E}) > > d(\text{M,E})$$

and Merge (Earth, Moon) as being only one world interacting with the Sun.

Overemphasizing the distance criteria leads to decompose U in two blocks: the Sun and (the Moon and the Earth in the other block).

Overemphasizing the mass criteria provides also an interesting decomposition: A completely hierarchical one due to the asymmetrical effect of mass.

IVb) DECOMPOSING INTERACTIONS AMONG THESE CLASSES

The analysis of the interactions affecting a class of individuals can be broken if it is still too complex by comparing these interaction according

to an other criteria in order to continue the decomposition. This makes Overemphasizing a key primitive of caricatural reasoning. The task of overemphasizing is to explicitly MAGNIFY some relation in order to generate a potential decomposition. This is the root of the transformation of the initial world into an extreme one where problem solving can this time be efficiently performed.

Furthermore two kind of informations are provided:

- The feature chosen responsible of the transformation, (mass, distance, level of friction ...)
- a compatibility relation that must not be violated that justifies the relative importance of an interaction in comparison to an other.

Keeping these two information is essential for several reason. First of all it will allow to explain according to what the caricature has been generated. Moreover the second kind of information allows to change caricatures if the compatibility criteria is not satisfied any longer.

Overemphasizing rules according to criteria are not exhaustive. More rules can be added and provide either heuristics or be domain dependant. But basic rules are given to the caricatural reasoner which are rather domain independent.

A typical rule which is very useful consist in generating an extreme world by overemphasis relations among parameters. for instance the relation

$$R1Mass[Sun] > mass[class\{Earth, Moon\}]$$

can be overemphasized in hierarchical decomposition of the interaction applying to respectively to the sun one hand and the moon and it's satellite in the other.

(Overemphasized R1):

$$R1Mass[Sun] > > mass[class\{Earth, Moon\}]$$

This overemphasized relation is kept as a time independant one since all the parameters involved are constants.

In this case the overemphasized relation will caricature the interaction of these two sub_systems by *hiding* the effect of the Earth and the Moon on the Sun. The symmetry is broken and so is the complexity.

The hierarchical decomposition generated, (by overemphasizing masses criteria) is a three layered one. Instead of merging the sun and the moon within one class, the analysis of Newton's law, by an overemphasis of mass relation will lead to the following decomposition.

- 1) Sun isolated system
- 2) Motion of earth governed by the interaction of Sun
- 3) Motion of the moon governed by interaction of Earth temporarily *ignoring* the sun.

The simulator can be feed properly with several possible caricatures:

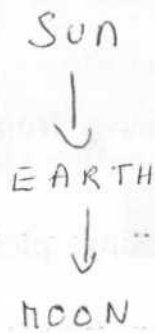
Motion of $U = \{Sun, Earth, Moon\}$

is transformed in several simulation tasks. (each of which are straightforward in comparison to the initial task). The Simulator is confronted to several simulation tasks. All are much simpler than the initial one. The choice of these simulation task has been generated by the caricatural reasoner.

V COMBINING CARICATURES

The next task is to put back together the different caricatures in order to attempt to have a more global view of the Universe (Both from a spatial and temporal point of view). The combination of caricatures is twofold: It is time dependant, and tends to assemble the behavior of the different class of individuals that have or have not been merged yet. The way of combining caricatures depends of the kind of decomposition of the universe which has been generated.

A) Simple Cases In the case where interactions among individuals has been broken among classes. Then the basic task is to simply combine the different motions. This is what happens in the case where the emphasis has been set on distance or on masses in the first basic examples.

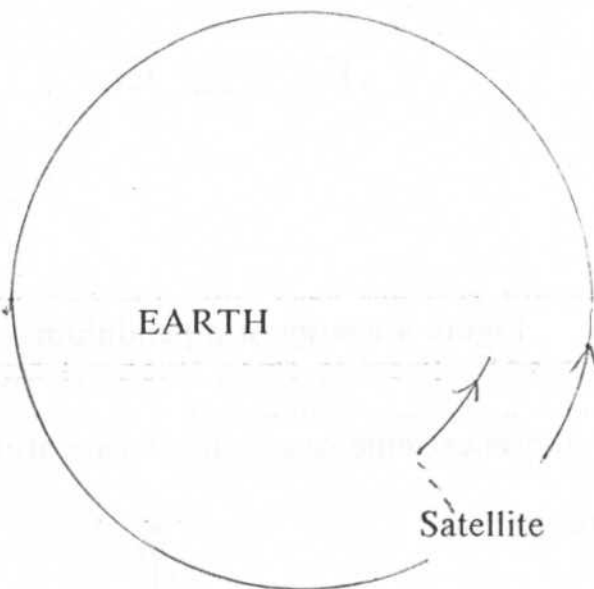


Overemphasis on Mass



Overemphasis on distance

B) MYTHICAL TIME But a more interesting way to combine caricatures, is obtained by introducing a mythical time during which a temporarily ignored interaction is reintroduced. (The case of a satellite of the sun the friction effect is not evaluated directly, but only once an ideal period has been accomplished). The combination of caricatures then integrates ignored phenomena just as if they would only modify the initial inputs of the overemphasized one.



Almost periodical phenomena

C) LIMIT ANALYSIS

The third way to combine caricature is through limit analysis. In such cases there is a complete global caricature allowing to consider all the individuals but the change through time violates the initial conditions according to which the overemphasizes has been performed. (A typical

case is Voyager Caricatures must change when moving away from the sphere of attraction of the Earth and getting ready to land on the Moon).

The second way of combining caricature provides surprising pictures. Here is a more detailed analysis of how it works.

The Damped Spring Revisited

Performing caricatural reasoning while integrating reasoning about time may lead to change what is ignored or overemphasized with time. Doing so can be done while mainly relying on the same primitive concepts. Consider the case of an oscillator, a mass on a spring, a pendulum, an RLC circuit,....and let's try to provide caricatures of its behavior:

Let us describe the world of an oscillator using energy functions: the different forms of energy considered are the potential energy, E_p , the kinematic energy, E_c , and the loss of energy due to friction: E_f



Figure 3 A pendulum



Figure 4 energy of a pendulum

The behavior of an oscillator, allows extreme cases: Basic caricatures:

Extreme_world: Overemphasize(mass)

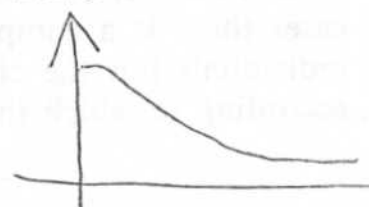
C1: Ignore(E_f) $\Rightarrow$ No loss of energy
 $\Rightarrow E_p + E_c = \text{cte}$
 $\Rightarrow$ Oscillatory motion, and no decay.



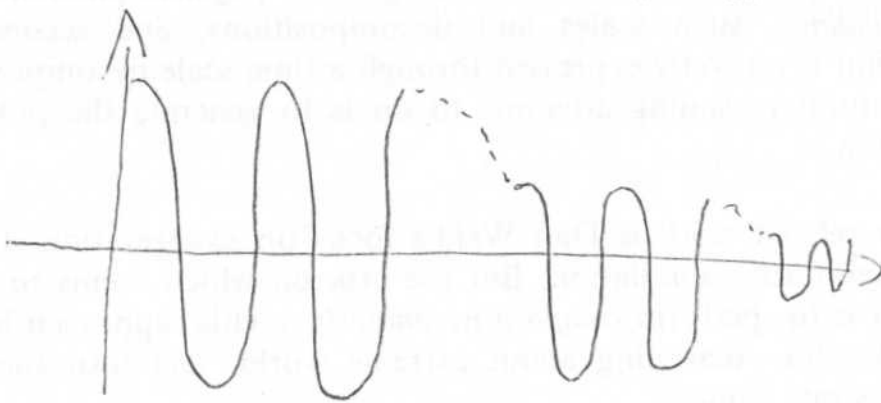
Extreme_world: Overemphasize(friction)

C2: Overemphasis(friction_coefficient) $\neg$ ignore(E_f) $\Rightarrow$
 hidden(velocity)

Overemphasis(friction) $\Rightarrow$ No oscillation.



The task of combining the basic caricature requires introducing mythical time. During this mythical time temporarily ignored interactions have their aggregated effect integrated: Combining totally damped spring and a one with perpetual motion. Instead of integrating friction all through simulation which kinds of slows down the qualitative simulation process. It is only integrated periodically as a transition arriving during a "mythical time".



Combined Caricatures of an oscillator

RELATED WORK

Let us try to put back this paper in perspective by comparing it with several related approaches:

1)

Ernie Davis has attempted to enhance qualitative simulation by extending Order of Magnitude Reasoning and integrating it in dynamic models. This work provides a clear formal basis. It refines the representation of a dynamic system, while keeping a hierarchical structure

(as introduced in FROG) in the quantity space and the time space and links these scales. Although it provides more information, the complexity of the analysis seems to be significantly increased.

On the contrary Caricatural reasoning attempts to extends and adapt the *features* of the order of magnitude reasoning instead of extending the calculus.

2)

Ben Kuipers, recently enhanced qualitative simulation for complex process, by introducing time scale abstraction. This scale *uses* a structure among dynamic process (a near decomposition of the different interactions) But this time scale is a *given* in this approach

An important part in the art of reasoning about physical phenomena is first in *finding* such scales and decompositions, and second the decomposition is not only expressed through a time scale decomposition. What caricatural reasoning attempts to do is to generate the potential decomposition.

3) Another related work is Dan Weld's focus on exaggeration. It also focus on quantitative simulation. But the task on which seems to focus exaggeration is to perform *comparative analysis* . This approach has an obvious link with reasoning about extreme world, and introduces an ability to generate some.

It differs from caricatural reasoning in it's task. Comparative analysis using exaggeration is *not a way to enhance the simulation of complex process*, but rather highlights the interest of focusing on extreme world to reason about the effect of a perturbation in a system's behavior.

4) Addanki's work on complex physical system identifies the importance of investigating ways to combine combining models and finding relevant models according to the problem solving task involved. His work on Graph of models seems to be the backbone for an investigation of complex process. It captures this kind of traditional way knowledge about physical domain is structured in books

But this framework does not inform us at least today about the art of generating initially models.

Conclusion

Caricatural reasoning tends to enhance reasoning about physical phenomena, by generating and combining extreme worlds in dynamic process to overcome the complexity of a brute force analysis. It is a generalization of order of magnitude reasoning which only enhances reasoning in the quantity quantity space. It is not an extension of the calculus but a generalization of the underlying features of Order of Magnitude Reasoning. This generalization draws it's inspiration from the traditional way of reasoning about physical phenomena. Caricatural reasoning structures the universe and transforms it in order to nearly decompose the interaction and keep their effect tractable. It forces to overemphasize explicitly characteristics of the worlds taking advantage of the specificity of the phenomena and generates extreme worlds. Caricatural reasoning as order of magnitude reasoning tries to capture what makes the specificity of reasoning about the physical world.

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