GIREP

Conference 2006 - Modelling in Physics and Physics Education

Program and Abstracts

August 20-25, Amsterdam, The Netherlands

Amstel Institute
University of Amsterdam

Proceedings
GIREP Conference 2006

August 20 – 25, Amsterdam, Netherlands

Modelling in Physics and Physics Education

To the grand philosophical question: "*What is man*?"
Aristotle answered:
"*Man is a rational animal*."
Modeling Theory offers a new answer:
"*Man is a modeling animal*!"
Homo modelus!

see Hestenes, p. 34

Editors:
Ed van den Berg
Ton Ellermeijer
Onne Slooten

Organized by:
Groupe Internationale de Recherche sur l'Enseignement de la Physique (GIREP)
AMSTEL Institute, Faculty of Science, Universiteit van Amsterdam

With the support of:
European Physical Society
City of Amsterdam
University of Amsterdam
Association DBK-na
Center for Microcomputer Applications

People in charge
Ton Ellermeijer
Ed van den Berg
AMSTEL Institute
Universiteit van Amsterdam

International Advisory Committee
Michele D'Anna, Switzerland
Ton Ellermeijer, Netherlands
Manfred Euler, Germany
Helmut Kuehnelt, Austria
Marisa Michelini, Italy
Rosa Maria Sperandeo Minea, Italy
Vivien Talisayon, Philippines
Dean Zollman, USA

Local Organizing Committee
Ton Ellermeijer (Chairman)
Ed van den Berg (Co-chairman)
Jasper Bedaux
Daday van den Berg
Margaret Fuller
Piet Geerke
Hans Hulst
Lodewijk Koopman
Ewa Kedzierska
Leentje Molenaar
Matti Molenaar
Piet Molenaar
Cees Mulder
Johan van de Ridder
Frank Schweickert
Diederik Slob
Peter Uylings
Barbara van Ulzen
Chris van Weert
Olga Zika

How to contact GIREP and to become a member:
Secretary: *Gorazd Planinsic*, University of Ljubljana, Faculty of Mathematics and Physics, Jadranska 19, SI-1000 Ljubljana, Slovenia
(fax: +386 (1) 2517281,
E-mail: gorazd.planinsic@fiz.uni-lj.si
Website: http://www.girep.org/

Gemeente Amsterdam

Preface

This book and CD contain almost all papers presented at the 2006 Amsterdam GIREP Conference:

The review process for papers was as follows: The chairperson of each paper session conducted a first review and recommended whether or not a paper should be published in the CD proceedings on the basis of relevance and quality and whether or not the paper should be considered for the book. A second review was conducted by reviewers after the conference. Papers receiving two positive book recommendations were accepted for the book version. Papers with one positive book recommendation went through a third review by the editors. Poster papers were reviewed by one reviewer.

All papers in the final version were posted on the web and authors were asked to check for major errors which might have slipped in somewhere in the word processing towards the final format.

All book papers have also been included on the CD. The CD also includes the photo collection of the conference.

This book and CD constitute one product with one ISBN number. When referring to any paper, whether in the book or on the CD, the reference should be:
[Author name](2008).[paper title]. : E. van den Berg, A.L. Ellermeijer, O. Slooten (Eds.), Modelling in Physics and Physics Education, [page number]. Amsterdam: AMSTEL Institute, University of Amsterdam.

ISBN 978-90-5776-177-5
Proceedings GIREP conference 2006 (August 20 – 25, Amsterdam, Netherlands): Modelling in Physics and Physics Education
Photographs by: Andrea Denotti
Editors: Ed van den Berg, Ton Ellermeijer, Onne Slooten.
Cover: Diederik Slob
Publisher: University of Amsterdam
Printed by: Alphabase, Alphen aan den Rijn, Netherlands

Table of Contents

PREFACE **3**

INTRODUCTION **4**

TABLE OF CONTENTS **9**

PLENARY SESSIONS **19**

Models of / for Teaching Modeling *20*
Piet Lijnse

Notes for a Modeling Theory of Science, Cognition and Instruction *34*
David Hestenes

Embedding Modelling in the General Physics Course: Rationale & Tools *66*
Vitor Duarte Teodoro

Measuring and Improving Student Mathematical Skills for Modeling *78*
Ronald K. Thornton

An Instruction Model for Modeling with simulations: How to help student build their own model with simulations *91*
Fu-Kwun Hwang

Motivating Teachers and Pupils to engage with Modeling. *101*
Laurence Rogers

PHOTOGRAPHS **115**

Modeling in the Classroom: Linking Physics to Other Disciplines and to Real-life Phenomena *121*
Michele D'Anna

Challenges and Opportunities in Computational Modeling *137*
Ian Lawrence

Developing an Appropriate Understanding of Scientific Modelling in Physics Instruction: Examples from the Project "Physics in Context" *149*
Silke Mikelskis-Seifert

System Dynamics Modeling in Fluids, Electricity, Heat, and Motion Examples, Practical Experience, and Philosophy *166*
Hans U. Fuchs

SYMPOSIA **189**

MODELING ASSESSMENTS OF INNOVATIVE PHYSICS COURSES 190

Symposium Overview *190*
Robert Fuller, Leslie Wessman & Graham Dettrick

Response to 'Modeling Assessments of Innovative Physics Courses' *197*
Frits L Gravenberch

PROBLEMS IN THE TEACHING OF ENERGY: HISTORICAL BURDENS OF PHYSICS 200

Symposium Overview *200*
Corrado Agnes, Michele D'Anna, Holger Hauptmann, Friedrich Herrmann, Michael Pohlig & Joel Rosenberg

COMPUTATIONAL MODELING ISSUES IN AND AROUND PHYSICS COURSES: WHY, WHAT, HOW AND WHITHER? 211

Introduction to the GIREP-2006 symposium on Computational Modeling Issues for Physics Courses *211*
Norman Chonacky

How Much and What of Computing for Physics Education? *216*
Hans-Joachim Bungartz

ACTION ON STAGE: WAYS TO UNIFY CLASSICAL AND QUANTUM PHYSICS USING THE ACTION MODEL 222
Action on Stage: Historical Introduction *222*
Jon Ogborn, Jozef Hanc, Edwin F. Taylor
A First Introduction to Quantum Behavior *230*
Jon Ogborn
What is the action model? Introducing and modeling principles of least action. *237*
Jozef Hanc
Use, Abuse, and Unjustified Neglect of the Action Principle *245*
Edwin F. Taylor

PAPER AND POSTER SESSIONS 251

MODELING IN PHYSICS EDUCATION 252
Modeling in Non-linear Physics *252*
A. Muñoz Diosdado
A Methodology to Study Students' Explanatory Models for Buoyant Force: Spiraled Exploratory Inquiry and Hypotheses Testing *259*
Estela Alurralde & Julia Salinas
Learning with a Virtual Camera – The Use of Multiple Representations for Learning *266*
Raimund Girwidz & Thomas Rubitzko
Models for Physics Teachers from the World of Pictures and Sounds *273*
Dorothy Sebestyen
Easy Java Simulation: A Modeling Tool for Physics Teaching and Learning ... *278*
Fu-Kwun Hwang
What Goes Up, Must Come Down; Modeling of Tidal Movement by Students *286*
L. van Gastel, A. Heck, P. Uylings
Teaching Wave Physics Through Modeling Images: Use Of Cabri® To Address Water Waves Geometrical Models And Basic Laws *299*
Gabriella Monroy, Italo Testa & Sara Lombardi
LEARNING QUANTUM MECHANICS 308
Visualization of Hydrogen Atom States *308*
Zdeňka Broklová, Jan Koupil
LEARNING ABOUT WAVES AND SOUND 318
Hear-and-See Tool for Learning Basic Acoustics *318*
Arcadi Pejuan
LEARNING ASTRONOMY 326
Project based Astrophysics with Role Playing *326*
Andreas Redfors
Teaching future teachers basic astronomy concepts *332*
Ricardo Trumper
VARIOUS PHYSICS 341
Modelling dynamical equilibrium in emission and absorption of radiation *341*
Allasia D. & Rinaudo G.
A Proposal for the Use of Structural Models in Physics Teaching: the Case of Friction *348*
Besson U., Borghi L., De Ambrosis A. & Mascheretti P.
TEACHING PHYSICS CONCEPTS 355
Year 12 Students' Mental Models of the Nature of Light *355*
Peter Hubber
LABORATORY ACTIVITIES IN PHYSICS EDUCATION 362
Optics for the Blind *362*
Neva Capra, Fabrizio Logiurato, Beniamino Danese & Luigi M. Gratton

What is the action model? Introducing and modeling principles of least action.

Jozef Hanc[10]
Institute of Physics, P. J. Safarik University in Kosice, Slovakia,

Abstract

The Action Principle predicts motion using the scalars energy and time, entirely avoiding vectors and differential equations of motion. Action is the tool of choice when we want to specify both initial and final conditions. Maupertuis-Euler action finds the trajectory when initial and final positions are prescribed in advance, but requires that energy be a constant of the motion. Hamilton action finds the worldline when initial and final events are prescribed in advance and easily describes motion when potential energy is a function of time as well as position. A simple toolkit of motion tells us when to use action, when to use Lagrange's equations, and when we must return to the vector methods of Newton. The original Euler method of handling action also provides a basis for computer modeling. Interactive software allows students to employ basic concepts of the principle of least action and increase conceptual understanding.

Least action approach in teaching

The least action principle approach, so important for modern physics, is widely considered to be a difficult topic and is usually only used in advanced mechanics textbooks and courses. Why does it seem a peculiar way to introduce and teach classical mechanics? Why is action as a physical quantity understood as being very abstract and unsuitable for introductory physics, despite the fact that it is a scalar very similar to energy – one of the central concepts of introductory courses?

The reasons are that in the majority of standard advanced texts [like Landau & Lifschitz 1976, Goldstein et al 2002, Marion & Thornton 2003, Hand & Finch 1998], — (1) the mathematics used is *the calculus of variations*, which is not part of the common mathematical toolkit acquired at introductory college level; (2) action is usually introduced extremely briefly and is only used for a quick variational derivation of Lagrange's equations; (3) action is not immediately illustrated by examples; texts typically include no or a very few examples; (4) there is also no study of the properties of action after introducing it, since they are taught at the end of courses and texts, (5) and finally you find no computer modeling, which means that students cannot obtain direct experience and intuition.

So the important question is how to introduce least action principles? Our experience says that it is possible in the frame of introductory courses provided that we concentrate on the following crucial issues:

[10]email: <jozef.hanc@upjs.sk>

- *Starting with one dimensional cases and using a powerful graphical language*. More general cases only bring in more complicated mathematical expressions, but essentially nothing new in physics ideas
- *Using concrete, but easily generalizable examples.* We have chosen Newton's falling apple, but the arguments will work for any reasonable potential energy function.
- *Building a clear connection to Newton's laws* in terms of comparison.
- *Using* ingeniously *simple original arguments* of the greatest physicists and mathematicians of all times: (1) *Newton's* argument from his celebrated *Mathematical Principles of Natural Philosophy* (1687) and (2) *Euler's* argument from his pioneering work on the variational calculus *The method of finding curved lines enjoying properties of maximum or minimum* (1744). As result we will not need advanced mathematics (all arguments require only high school algebra such as expressions $(a \pm b)^2$ and basic properties of parabola). Moreover we also obtain an excellent foundation for computer modeling, which is important in getting good intuition and experience.

So how does classical mechanics explain the motion of a falling apple? We will show three different approaches – tools for answering this question: *Newton's laws*, *Hamilton's* and *Maupertuis'* principle of least action. As we will see below, together they form a simple toolkit of mechanics in which the question being asked about any system determines directly which tool should be used to predict the motion of that system.

Motion of a falling apple from different points of views

Newton's laws of motion

We start with the well-known Newton's laws of motion, which are already taught at high schools. Firstly Newton says: "Give me the initial state of the apple, which means the initial position and velocity of the apple".

However giving the initial velocity and position means experimentally measuring two nearby positions at very close instants. In this case the initial (and indeed any) velocity is graphically nothing else than the slope of the *position vs. time graph,* or in the language of spacetime physics the slope of the apple's *worldline*.

Then Newton offers us his laws of motion and answers the questions: *What happens next with the apple? That is, what is the position of the apple at the next instant, if there is Earth's gravity or in general some force F (see fig.1)?*

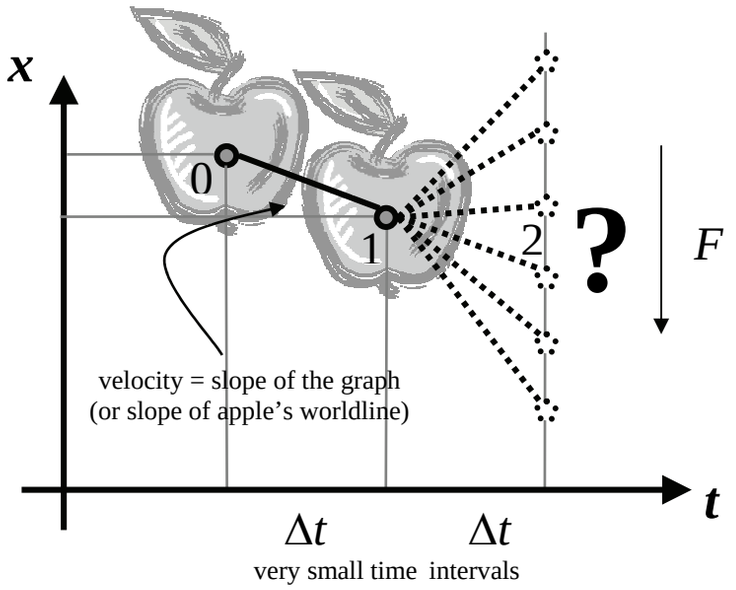

Figure 1. Newton's laws answer the question what is the position of the apple at the next instant, if we know the initial velocity and position or in other words, we know two very nearby positions of the apple.

If there were no acting force, then according to the first law of motion, the principle of inertia, the apple would continue in motion at the same velocity, so graphically it would follow a straight-line worldline (see fig.2). Instead Earth's gravity (or generally some force *F*) causes a component of motion in the direction of the applied force, as described by the second law of motion, the momentum principle $m\Delta v = F\Delta t$. Competition between these two tendencies results in the parallelogram of which the diagonal represents the worldline of the actual motion (fig.2).

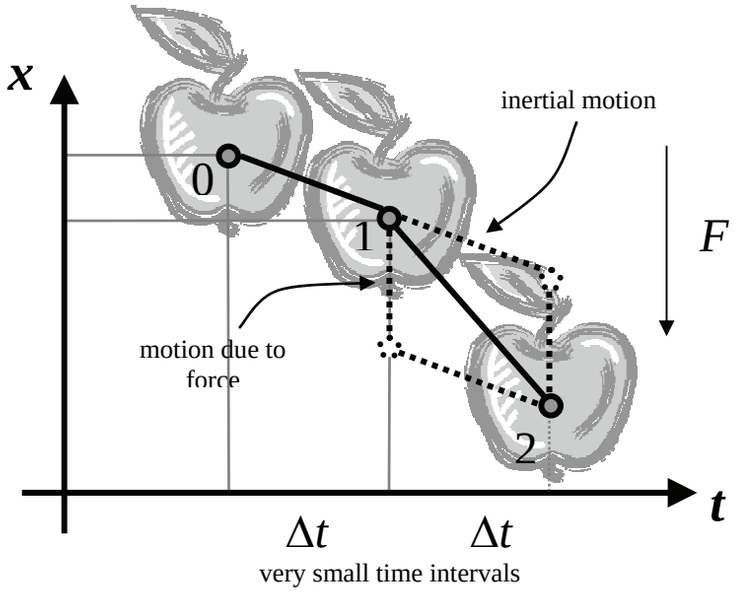

Figure 2. According to Newton's laws the motion of the apple is produced by two "effects": the apple's inertial motion at constant velocity, if no forces act upon it and the motion due to an acting force F. The net motion is then given by the diagonal of the parallelogram of the separate motions that would have occurred.

This process of constructing worldlines (which is conceptually the same for trajectories) is simple, repetitive and universally applicable, so it

provides a first-rate foundation for computer modeling. Since today's computers are very fast there is really no need for fancy algorithms in introductory physics teaching. To get a better approximation to the actual motion we simply take smaller time steps.

This numerical method appears in some classics physics texts notably in Chapter 9 in Vol.1 of Feynman's lectures on physics (1964). But it is also very effectively applied in the modern introductory physics curriculum, e.g. in *Modern Mechanics* of Chabay and Sherwood (2002) or in *Unit N* of Moore's Six Ideas That Shaped Physics (2003).

Hamilton's principle of least action

Now we apply a first action model to our falling apple based on energy concepts and Hamilton's least action principle. Hamilton tells us: "Give me both initial and final positions and times of the apple," called in spacetime physics *events*. If we specify the initial and final events in advance, then Hamilton's principle can successfully answer the following question: *What is the middle event for the apple? Or which worldline is followed by the falling apple between the initial and final events, if the apple has potential energy U(x) (see fig.3)?*

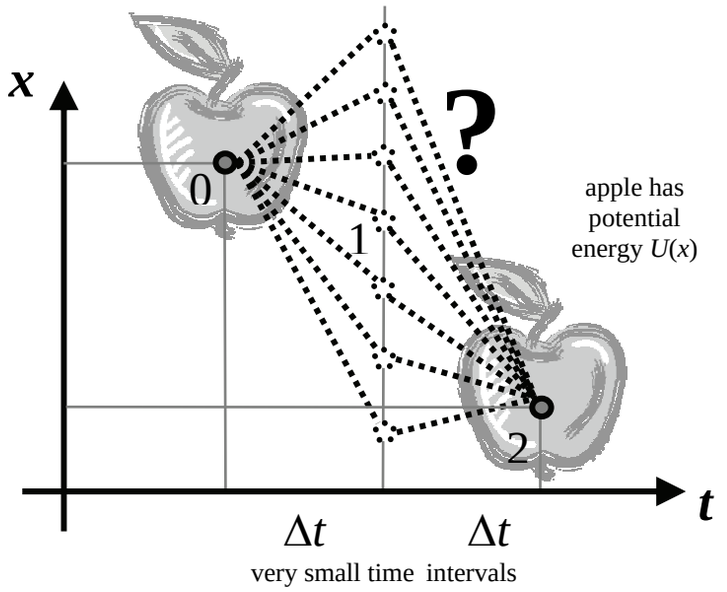

Figure 3. Hamilton's principle answers the question what is the middle position or more generally the middle event for the apple, if we know the apple's initial and final events.

Now what special property does the actual worldline obey? The principle of least action discovered by Hamilton says that the apple follows *the worldline for which the average kinetic energy minus the average potential energy is as little as possible* or put more briefly worldline has *the least action*, because Hamilton's action *S* is defined as

$$S \equiv \begin{pmatrix} \text{difference between} \\ \text{average kinetic and potential} \\ \text{energy along the worldline} \end{pmatrix} \cdot \begin{pmatrix} \text{time duration} \\ \text{of motion} \end{pmatrix} \quad \text{or}$$

$$S = \left(\langle K \rangle - \langle U \rangle\right) \cdot (t_{final} - t_{initial}) \qquad (1)$$

Using integral calculus the definition (1) has the form

$$S = \int_{t_{initial}}^{t_{final}} (K - U)dt = \int_{t_{initial}}^{t_{final}} L dt \,, \qquad (2)$$

where the difference $K - U$ is called the *Lagrangian L*, the quantity that appears in Lagrange's equations of motion.

In the case of our falling apple (and also in general case for small Δt) it is easy to calculate all terms in the expression (1) for action S along any worldline 012 (fig. 3). The time duration $t_{final} - t_{initial}$ equals $2\Delta t$. The average kinetic energy $\langle K \rangle$ is given by $(K_A + K_B)/2$, the average of kinetic energies for the first and second segment of the worldline, that is, by $(1/2)(mv_A^2/2 + mv_B^2/2)$, where $v_A = (x_1 - x_0)/\Delta t$ and $v_B = (x_2 - x_1)/\Delta t$.

We now have to pay attention to the potential energy $U(x)$. The shortness of Δt allows us to approximate $U(x)$ by a linear function Cx in the region near point 1. (An additive constant is not important, because it is always zero after an appropriate choice of a reference point.) For the apple constant C is positive and equals mg. Generally we will consider it here as some positive constant. From the viewpoint of the force concept used previously in Newtonian analysis it represents a force $F = -\Delta U/\Delta x = -C\Delta x/\Delta x = -C$, a force in the downward direction. Then $\langle U \rangle$ equals $(U_A + U_B)/2 = (1/2)[C(x_0 + x_1)/2 + C(x_1 + x_2)/2]$. Since the events 0 and 2 are fixed and only position of the middle event 1 is variable, the apple's action S must be only a function of x_1, in which case it is a quadratic function.

To find a worldline with the least action therefore means that we must vary and find a position x_1 which makes the action a minimum. There are two natural ways to do this. One is the trial-and-error method, perfectly suited for a computer which can quickly calculate and compare the action (1) for millions of worldlines. The detailed description of computer modeling based on the so-called Euler variational method is described in our symposium contributions *Action on Stage* (see fig. 1, 2) and *Use, Abuse, and Unjustified Neglect of the Action principle* (see fig. 1).

The second way to find the least action worldline is the use of mathematical methods. According to Hamilton's principle the action has to become larger, if we change the position x_1 of the middle event 1 of the

actual worldline by any small displacement δx. Using only high school algebra one can obtain the following expression for the corresponding change in action:

$$\delta S = S(x_1 + \delta x) - S(x_1) = \left(m\Delta v - F\Delta t\right)\delta x + 2\frac{m}{\Delta t}(\delta x)^2 \qquad (3)$$

Mathematically equation (3) represents a simple quadratic function with respect to δx whose graph is a parabola. The graphical method proves that the least-action worldline is identical with the worldline predicted by Newton's laws (fig. 4). The method gives students an intuitive and visual understanding of the meaning of the least action principle, as does the computer modeling described earlier.

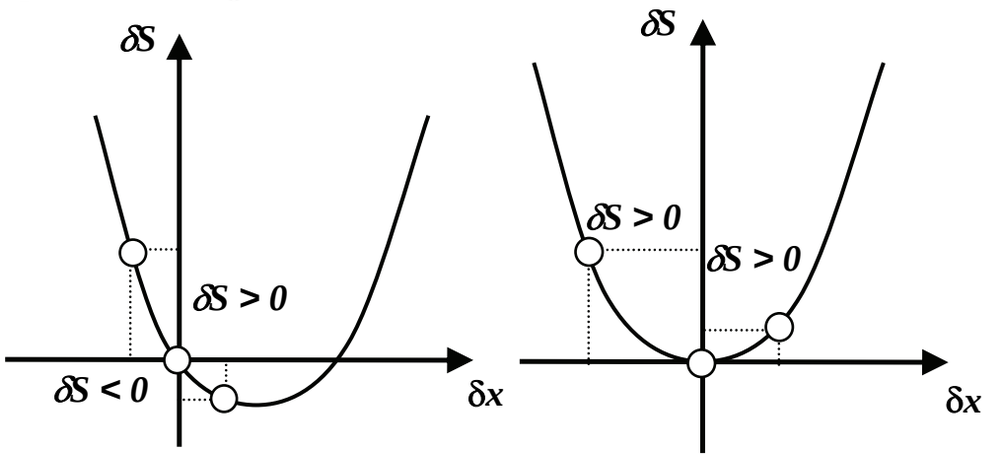

Figure 4. Both parts of the figure display changes in action with respect to displacement δx. In the left part the linear term in eq. (3) is not zero, i.e. $m\Delta v - F\Delta t \neq 0$. The action demonstrates both negative and positive changes, so the chosen worldline does not yield a minimal action. In the right part the condition that the linear term be zero, $m\Delta v - F\Delta t = 0$, gives a required minimum.

Maupertuis' principle of least action

Finally we will analyze the apple's motion from the viewpoint of the second least action principle called Maupertuis' principle of least action. Maupertuis requires: "Consider a conservative system. Give initial and final position and total energy of the system."

The total energy and its conservation (we again assume knowledge of the potential energy), lead to knowing the apple's initial speed, which implies two possibilities of motion – with the upward or downward direction. But in the case of the falling apple we are interested only in the downward motion. Then according to Maupertuis we are able to answer the question: "*What is the apple's final event, if we know its initial and final positions (see fig. 5)?*"

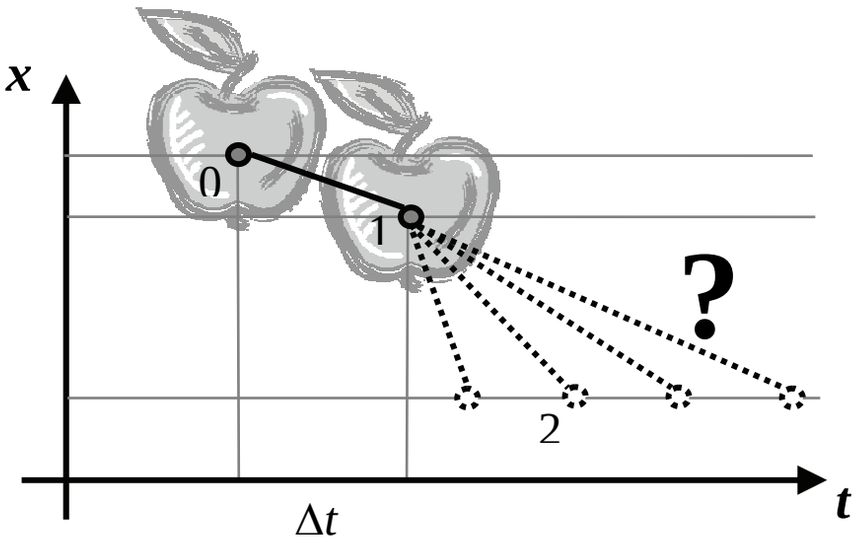

Figure 5. The Maupertuis action principle can answer the question "What is the apple's final event, if we know its initial and final positions?"

Since we consider a conservative system the actual motion of the apple must satisfy energy conservation. From Newtonian mechanics we know that it is the same motion as predicted by Newton's laws. Everything seems to be good. So the natural question arises: where is the action principle? But we now see that we did not realize that energy conservation alone actually allows other worldlines, strange and unrealistic with respect to Newton's laws. One example is shown in fig. 6. How to recognize a motion as actual or unrealistic?

The criterion is just the Maupertuis action. It can be shown in a very similar way as in Hanc et al. 2005 that a useful graphical tool in the case is the velocity vs. position diagram called in mechanics *the phase diagram*, which says that for unrealistic worldlines the area under *the phase curve* is always bigger than for the actual one. This geometric idea provides a foundation for the definition of the second version of action, Maupertuis action *W*:

$$W \equiv \begin{pmatrix} \text{area under} \\ \text{phase curve} \end{pmatrix} \cdot \begin{pmatrix} \text{object's} \\ \text{mass} \end{pmatrix} \quad \text{or} \quad W = \int_{\substack{\text{initial} \\ \text{position}}}^{\substack{\text{final} \\ \text{position}}} mv\, ds \qquad (4)$$

Summarizing we can say that Maupertuis' principle of least action tells the falling apple to move so that the product of mass and area under the phase curve has the smallest possible value (subject to energy conservation). So far as computer modeling is concerned, it is the problem as before.

Acknowledgments. The work was partly supported from the grant of Slovakian cultural and educational agency (KEGA), Project No. 3/3005/05.

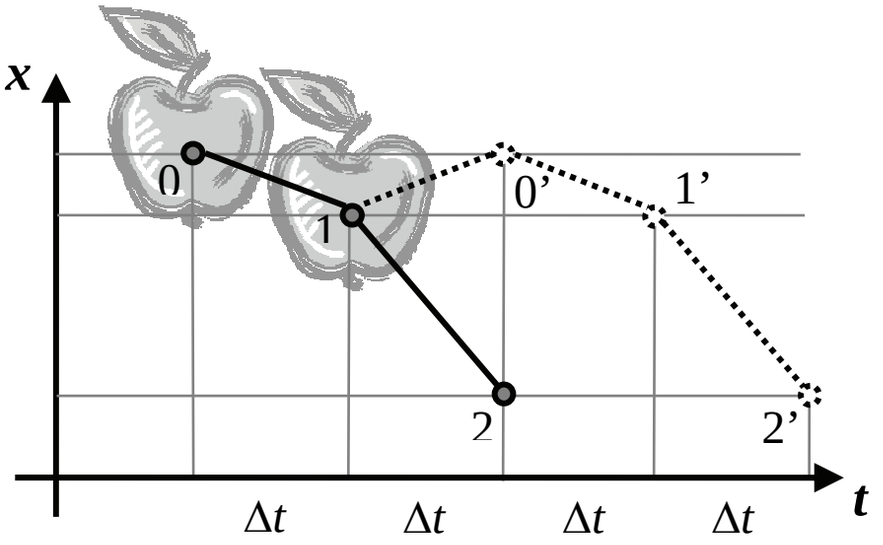

Figure 6. Both depicted worldlines 010 and 010’1’2’ satisfy energy conservation, but only one describes the real motion.

List of references

Chabay, R.W., Sherwood, B. A. (2002) Matter and Interactions: I. Modern Mechanics. John Wiley & Sons, New York. <http://www4.ncsu.edu/~rwchabay/mi/>

Euler, L. (1744). Methodus Inveniendi Lineas Curvas Maximi Minimive Proprietate Gaudentes sive… Laussanne and Geneva; see also chap. 2 in Goldstine H. H. (1980), A History of the Calculus of Variations from the 17th Through the 19th Century. Springer-Verlag, New York.

Feynman, R.P., Leighton, R.B., Sands, M. (1964) The Feynman Lectures on Physics. Addison-Wesley, Reading, MA, Vol. I

Goldstein, H., Poole, Ch., Safko, J. (2002). Classical Mechanics. (3rd ed.) Addison–Wesley, Reading, MA

Hanc, J., Taylor, E.F., Tuleja, S. (2005). Variational mechanics in one and two dimensions. Am. J. Phys. (73), 603-610 (and references in the article) <http://www.eftaylor.com/leastaction.html>

Hand, L.N., Finch, J. D. (1998). Analytical Mechanics. Cambridge University Press, Cambridge, UK.

Landau, L. D., Lifshitz, E. M. (1976). Mechanics (3rd ed.). Butterworth-Heinemann, Oxford, UK.

Moore, T. A. (2003) Six ideas that Shaped Physics: Unit N - The Laws of Physics are Universal. McGraw Hill, New York. <http://www.physics.pomona.edu/sixideas/>

Marion, J.B., Thornton, S.T. (2003). Classical Dynamics of Particles and Systems (5th ed.). Thomson Brooks/Cole.

Newton, I. (1687) Philosophiae Naturalis Principia Mathematica, London; see also chap. 3 in Goodstein, D. L. et al (1999). Feynman's Lost Lecture …W.W. Norton, New York.