Appendix A
Diagrammatic Induction

It might seem as though one of the limitations of diagrammatic proofs is that they can only express specific statements, not general ones. If one wants to prove that the sum of all the angles in a triangle is 180°, it does not suffice to draw one triangle and to confirm (approximately) the statement. So how can one prove or even express a general statement using a diagram?

One possibility is by *inductive* proof, much in the same way that inductive proofs are carried out using mathematical formulae. An inductive proof does not need the special features of mathematical or logical formulae and can therefore be performed using other types of symbols as well. In fact, it is even not obvious how one should distinguish mathematical or logical formulae from other types of symbols such as diagrams (see, e. g., Goodman 1968, chapter IV, section 10).

In logic and mathematics one can, for example, prove by induction that a statement is generally true when it has been explicitly verified only for a finite number of special cases. This is possible by establishing a prescription of how all the special cases, one after the other, can be constructed, such that at each stage of the construction the truth of the statement is preserved. If such a prescription is available, the same inductive proof procedure should, therefore, be possible for any kind of symbol, including symbols that one calls diagrams, graphs or drawings. For example, the statement that the sum of the odd numbers up to $2n - 1$ equals n^2 can be proved by induction using either mathematical formulae *or* diagrams. Brown (1996, p. 253) also discusses this example; note, however, that he does *not* consider that the variant of the proof using diagrams is a proof by induction.

The standard proof using mathematical formulae is first to verify the statement for the first $n = 1$:

$$\sum_{j}^{1} 2j - 1 = 1 = 1^2. \tag{A.1}$$

A. Wüthrich, *The Genesis of Feynman Diagrams*, Archimedes 26,
DOI 10.1007/978-90-481-9228-1, © Springer Science+Business Media B.V. 2010

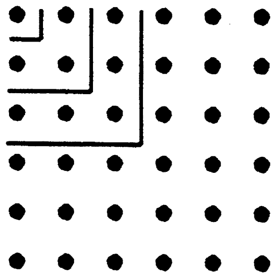

Fig. A.1 Diagram used to prove that the sum of odd numbers up to $2n - 1$ equals n^2 (Brown 1996, p. 251)

Next, one expresses the general sum up to $2n - 1$ in terms of the sum with one term less, that is up to $2(n - 1) - 1$:

$$\sum_{j}^{n} 2j - 1 = \sum_{j}^{n-1} (2j - 1) + 2n - 1. \tag{A.2}$$

Assuming that the statement holds for the sum with one term less, one obtains

$$(n - 1)^2 + 2n - 1 = n^2 - 2n + 1 + 2n - 1 = n^2. \tag{A.3}$$

Thus one has proved that if the statement holds for a sum up to a certain n, it also holds for the sum with one more term. Since the statement was verified for the lowest possible n, it holds for any n.

Therefore, proof by induction essentially hinges on one being able to construct one member of the class of objects about which one wants to derive a statement out of the previous member, relative to a certain ordering of the members in the class. Yet this can also be done using a *graphical* representation of the members of the class, in our case the odd numbers up to $2n - 1$. One can represent the sequence of odd numbers as sectors in a quadratic array of dots containing n^2 dots (see Fig. A.1). Then one can verify the statement $\sum_{j}^{n} 2j - 1 = n^2$ for the special case $n = 1$: one dot is the same as a quadratic array made up of one dot. The next member of the class is obtained by adding an L-shaped segment to the previous member in the lower right-hand side of the diagram, since the L-shaped segment contains an odd number of dots. Adding an L-shaped segment to a square results again in a square, the side of which contains one more dot than the original square. Therefore, if the statement is true for the previous member, it is true for the next member. Since any member of the class can be constructed by adding L-shaped segments, the statement is proved in its full generality.

Appendix B
Synopsis of Manuscripts and Principal Publications

On the following page, I give an overview of the notes and the publications by Feynman as well as the publications by Freeman J. Dyson, Hans Euler and the Japanese physicists working around Sin-Itiro Tomonaga that I discuss in my dissertation. I also include some of the publications by Julian Schwinger and Ernst C. G. Stueckelberg that might be of interest as regards the chronology of the development of Feynman diagrams. For the published work, I give the date of publication; for Feynman's notes, I give the approximate dates that seem most plausible to me on the basis of my reconstruction of the developments.

Manuscripts by Feynman		Publications by Feynman		Publications by others	
				1934	Stueckelberg
				1936	Euler
				1938	Stueckelberg
		1941	Wheeler and Feynman (conference presentation, see 'Minutes of the ...' 1941)	1941	Stueckelberg
		1942	PhD thesis (Feynman 2005)		
		1945	Wheeler and Feynman		
ca. 1946	*Dirac Equation b*, *Harmonic Oscillators b*			1946	Tomonaga
1946/47	Exchange of letters between Feynman and Theodore Welton (*Dirac Equation a*)				
ca. 1947	*Space-time approach to quantum electrodynamics*, *Dirac Equation h*				
ca. 1948	*Advanced Quantum Mechanics (at Cornell)*, *Theory of Positrons ...*	1948	RMP48 (April), CutOffCl (Oct.), CutOffQ (Nov.)	1948	Schwinger 1948a (Feb.), Schwinger 1948b (Nov.), RadReacI, RadReacII
		1949	Wheeler and Feynman 1949 (July), ThPos (Sept.), STQED (Sept.)	1949	RadReacIIIa, RadReacIIIb, RadTh (Feb.), SM (June)
early 1950s	*Helium*	1951	Feynman		

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Abbreviations

RMP48	R. P. Feynman (1948). 'Space-Time Approach to Non-Relativistic Quantum Mechanics'. In: *Reviews of Modern Physics* 20.2 (Apr. 1948), pp. 367–387.
ThPos	R. P. Feynman (1949). 'The Theory of Positrons'. In: *Physical Review* 76.6 (Sept. 1949), pp. 749–759.
STQED	R. P. Feynman (1949). 'Space-Time Approach to Quantum Electrodynamics'. In: *Physical Review* 76.6 (Sept. 1949), pp. 769–789.
RadTh	F. J. Dyson (1949). 'The Radiation Theories of Tomonaga, Schwinger, and Feynman'. In: *Physical Review* 75.3 (Feb. 1949), pp. 486–502.
CutOffCl	R. P. Feynman (1948). 'A Relativistic Cut-Off for Classical Electrodynamics'. In: *Physical Review* 74.8 (Oct. 1948), pp. 939–946.
CutOffQ	R. P. Feynman (1948). 'Relativistic Cut-Off for Quantum Electrodynamics'. In: *Physical Review* 74.10 (Nov. 1948), pp. 1430–1438.
SM	F. J. Dyson (1949). 'The S Matrix in Quantum Electrodynamics'. In: *Physical Review* 75.11 (June 1949), pp. 1736–1755.
RadReacI	Z. Koba and S.-I. Tomonaga (1948). 'On Radiation Reactions in Collision Processes. I.' In: *Progress of Theoretical Physics* 3.3, pp. 290–303.
RadReacII	Z. Koba and G. Takeda (1948). 'Radiation Reaction in Collision Process, II'. In: *Progress of Theoretical Physics* 3.4, pp. 407–421.
RadReacIIIa	Z. Koba and G. Takeda (1949). 'Radiation Reaction in Collision Process III1. First Radiative Correction for an Arbitrary Process Including Electrons, Positrons, and Light Quanta'. In: *Progress of Theoretical Physics* 4.1, pp. 60–70.
RadReacIIIb	Z. Koba and G. Takeda (1949). 'Radiation Reaction in Collision Process III2. First Radiative Correction for an Arbitrary Process Including Electrons, Positrons, and Light Quanta'. In: *Progress of Theoretical Physics* 4.2, pp. 130–141.

Cross-References

The bibliography partially functions as an index: At the end of each entry the pages on which the item is cited are indicated by the phrase "See p./pp. . . . ".

Classification of the Material from the Feynman Collection Held by the Caltech Archives

The Papers of Richard Phillips Feynman held by the Caltech (California Institute of Technology) Archives have been filed into labelled folders and boxes (91 in total). A finding aid is available at the Archives and online.[1] The Feynman Collection was processed by Charlotte E. Erwin, Carol Finerman and David A. Valone and completed on 1 July 1993. The finding aid was updated in September 2002. The Archives kindly permitted me to take digital photographs of parts of those folders which contained possibly relevant material for my area of investigation. Thus, from some of the folders I selected several series of folios, which I labelled, for the purposes of my research, *a*, *b*, *c*, etc., in the order that they appear in the folder. The particular folios in a series are referred to as the first, second, third, etc., folio in the series in the order that they appear in it, irrespective of any page-numbering system that Feynman may have applied to his notes. Note that under normal circumstances the folios made available to researchers are photocopies of Feynman's original papers. Therefore, Feynman's notes on the verso of a piece of paper appear as separate folios in the Archives. I have used the title given by the archivists to refer to a particular folder in a box, the numbers of which are given in the references below. For example, "*Dirac Equation a*, folio 11" refers to the 11th folio in series *a* from Folder 2 in Box 11, which was given the title "Dirac Equation" by the archivists. If no series label is given, then I have selected only one series of folios from the relevant folder (but the whole folder is not necessarily made up of only this one series).

I was able to date only one of the folios precisely (*Dirac Equation a*, folio 1, see page 80). Nevertheless, I indicate for each series of folios the approximate dates that seem most plausible to me on the basis of my reconstruction of the developments.

For internal use only, I have stored my selection of 588 folios in `jpeg` format in the digital library of the Institute of Philosophy of the University of Bern. On request, and with the agreement of the Caltech Archives, the Institute of Philosophy will grant interested researchers access to this material.

[1] The online finding aid is provided by the Online Archive of California, and is available at `http://www.oac.cdlib.org/findaid/ark:/13030/kt5n39p6k0`, last visited 12 July 2010.

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Dirac Equation h. (Ca. 1947). Eighth series of selected folios from Box 11, Folder 2. See pp. xv, xvii, 107, 108

Theory of Positrons; Self-Energy in an Atom; Radiation Scattering; Spreading Dirac Packet. (Ca. 1948). Series of selected folios from Box 13, Folder 1. See pp. xv, 128, and 129

Harmonic Oscillators b. (Ca. 1946). Second series of selected folios from Box 11, Folder 5. See p. 194

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