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A Historical Critique of Symmetry's Success Story

Starting point: "Symmetries have a special role in physics"

symmetries ~ math. invariance, group-theoretical structures (and more...)

special role --> ontology? epistemology? why?

--> "Symmetries have proven to be successful heuristic tools"

Case study: "applications of symmetry" in early particle physics

Received view: in the 1950s and '60s the application of symmetry (group theory) to model particle properties led to empirically successful models

My reconstruction:

different heuristic strategies used – strategies explicitly applying group-theoretical knowledge were the <u>least</u> successful

empirically successful group-theoretical notions were not generally regarded as more physically significant

Side remark: In the words of some practitioners at the time, the succesful structure were only "models" out of which a physically significant "theory" shoud be built

Aims of the case study:

- criticizing some historical claims of a success story
- demonstrating the many different dimensions of "applications of symmetry" - even in a very simple historical constellation: it's important to differentiate among them, but all of them play a role in scientific practice!
- pointing at how some dimensions may be relevant for discussing BSM-physics

Two important distinctions:

- diverging mathematical conceptualizations of the same technique

  e.g.: vector rotations in 3 dimensions VS. representation of the group O(3)

  N.B.: the difference exists also when historical actors know group theory!
- different attribution of physical significance to mathematical structures, with historical actors privileging specific structures above others

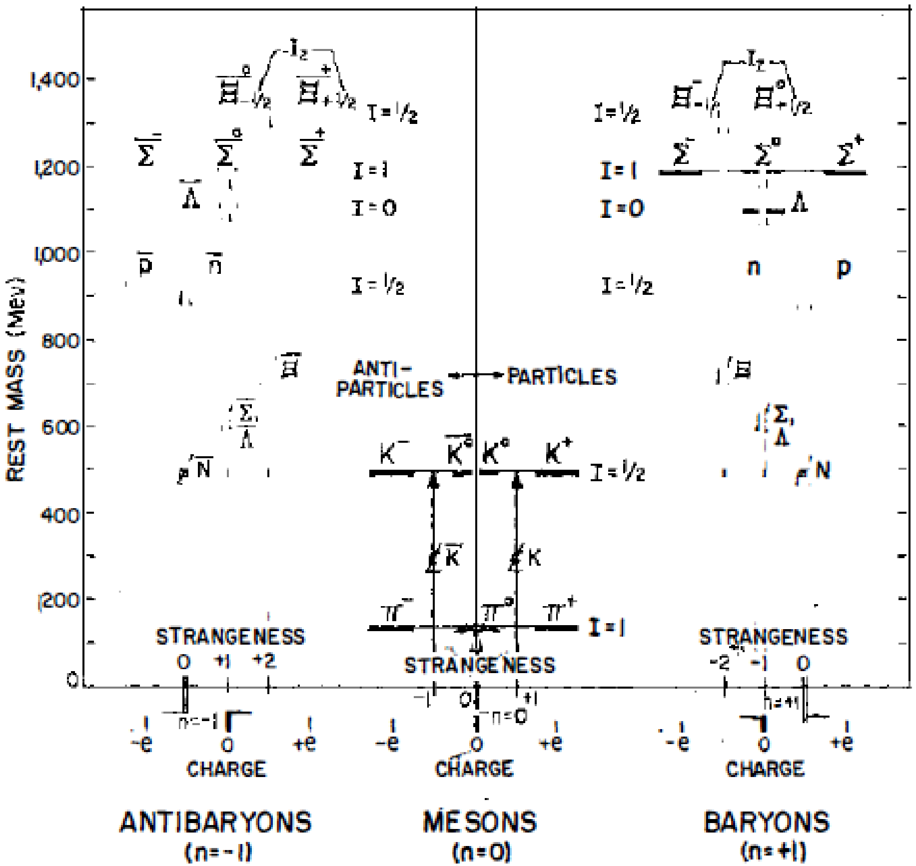
Case study: the Gell-Mann/Nishijima model and the quark model – and more precisely the attempts to use group theory to turn them into “theories”

~1947-54: many "new particles"!

1955-56 Gell-Mann/Nishijima model - classification of particles into "displaced isospin multiplets" - "strangeness" is the displacement.

Isospin: property conceived and manipulated in analogy to (non relativistic) spin – no explicit reference to SU(2)

1957 (figure): first diagrammatic representation of (displaced) isospin multiplets – primarily of physical, not group-theoretical properties!

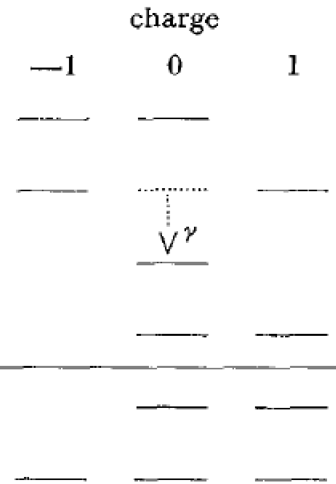


Spin had turned out to be the low-energy manifestation of properties linked to rotations in relativistic space-time → *could something similar be true for isospin?*

Proposals to expand isospin into an "isospace" in 3 or 4 dimensions using group-theoretical notions: Pais (1953a, 1953b, 1954) Rayski (1954), Cerulus (1956), Racah (1956), d'Espagnat&Prentki (1955, 1956, 1957) d'Espagnat and Prentki (1955): "Mathematical formulation of the Gell-Mann model"

"It is shown that an axiomatic formulation of the Gell-Mann model concerning elementary particles is possible. Different kinds of fields are formally introduced which are defined by their transformation properties in ordinary (Lorentz) space and isobaric space, the latter being three dimensional."

They introduce a new property U and remark: *"The values of U deduced from the theory turn out to be precisely those postulated in the Gell-Mann model. In fact a complete equivalence with this model is so obtained."*



particule	i	$q\ (i_3)$	
Ξ	$\frac{1}{2}$	$q = i_3 - \frac{1}{2}$	Fermions
Σ	1	$q = i_3$	
Λ	0	$q = i_3$	
N	$\frac{1}{2}$	$q = i_3 + \frac{1}{2}$	
θ	$\frac{1}{2}$	$q = i_3 + \frac{1}{2}$	Bosons
π	1	$q = i_3$	

d'Espagnat and Prentki give a diagram of the mathematical aspects of the Gell-Mann/Nishijima model

Group-theoretical efforts to expand the SU(2) isospin model to 3 or 4-dimensional space(time) are not empirically successful...

...later on, the model will be extended into SU(3) – without help from group theory!

1964: quark model (Gell-Mann, Zweig)

Gell-Mann/Nishijima model embedded in a SU(3) structure - origin of SU(3) was the Sakata model, which emerged without any reference to group theory

SU(3) structure explained as the combination of three fundamental (unobserved) entitites: “quarks” (Gell-Mann) or “aces” (Zweig)

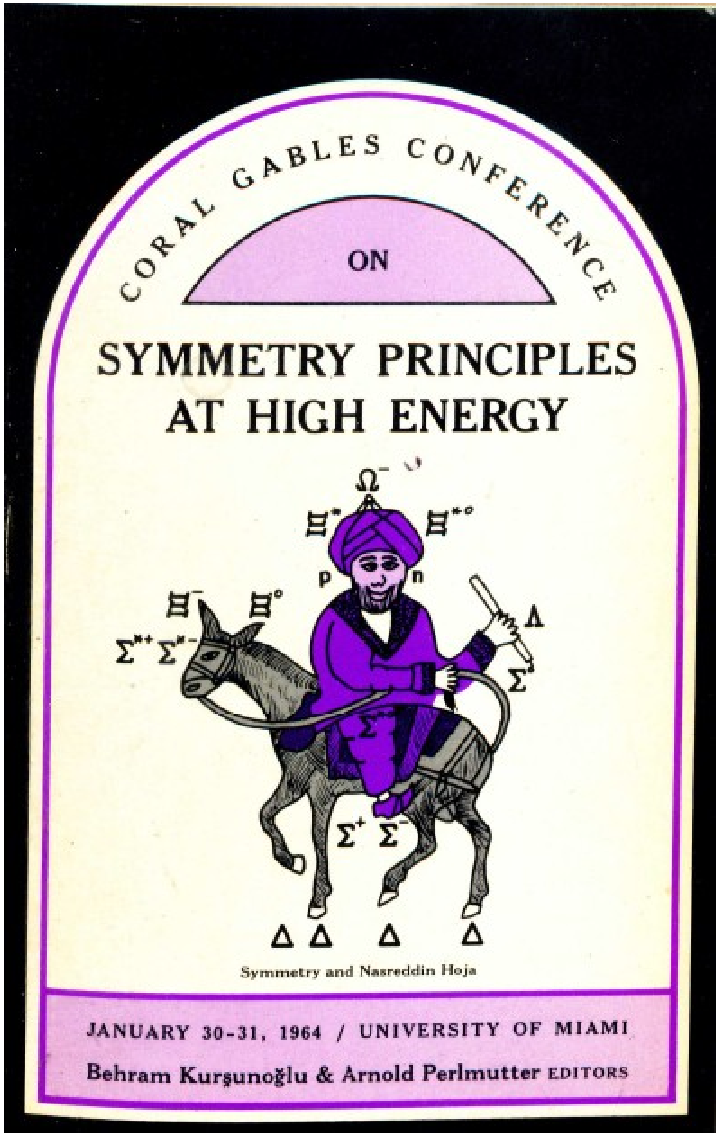
The quark model emerged from very different physical and mathematical practices than those of the authors trying to expand isospin into a new space or space-time - *the SU(3) structure was no guideline!*

a posteriori it has been claimed that SU(3) would have come earlier if physicists had known more group theory...

…but Pais, d’Espagnat, Racah etc. knew a lot of group theory!

Once SU(3) was there, mathematically-minded theorists started trying to connect it to relativistc space-time symmetries – meeting every year at Coral Gables (Miami) in a series of conferences from 1964 to 1968

Proceedings of the (1st) Coral Gables: particles and Nasreddin Hoja, a traditional Turkish "wise joker" figure much loved by Kursunoglu



Some participants 1st conf.: Asim Barut, Laurie Brown, Sydney Coleman, Cecile DeWitt-Morette, Sheldon Glashow, Nicholas Kemmer, Behram Kursunoglu (main organizer), Benjamin Lee, Robert Marshak, Yuval Neeman, Susumo Okubo, Julian Schwinger, Val Telegdi

Later also: Nicola Cabibbo, Bernard d'Espagnat, Murray Gell-Mann, Gerald Guralnik, Yoichiro Nambu, Robert Oppenheimer, Lochlainn O'Raifeartaigh, Abraham Pais, George Sudarshan, Bruno Zumino

A representative example of the general attitude:

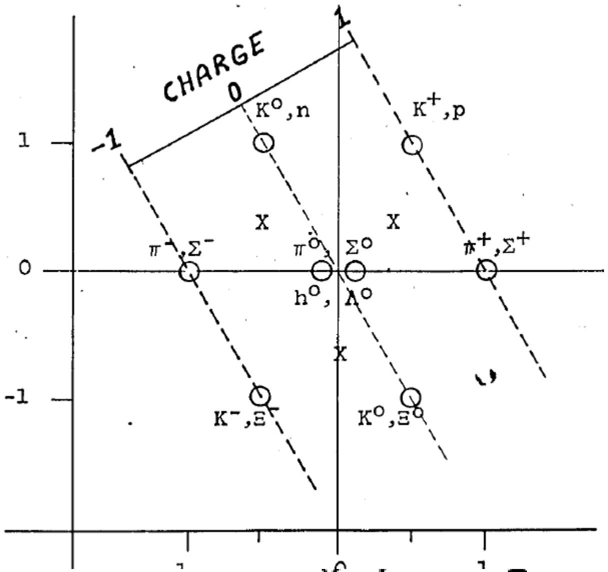
Kursunoglu (1st conf. Jan 1964): "A new symmetry group for elementary particles"

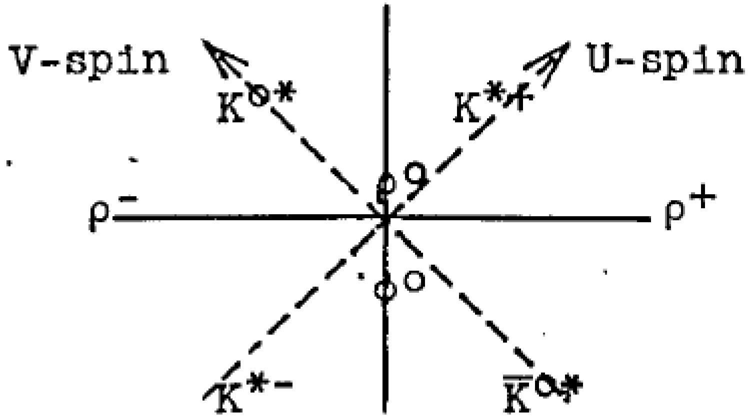
"The introducton of fictitious spaces like isospin space or unitary spin space, distinct from the space-time structure has long been recognized to be quite unsatisfactory for further progress towards a real understanding of the dynamical principles unterlying elementary particles interactions [...]

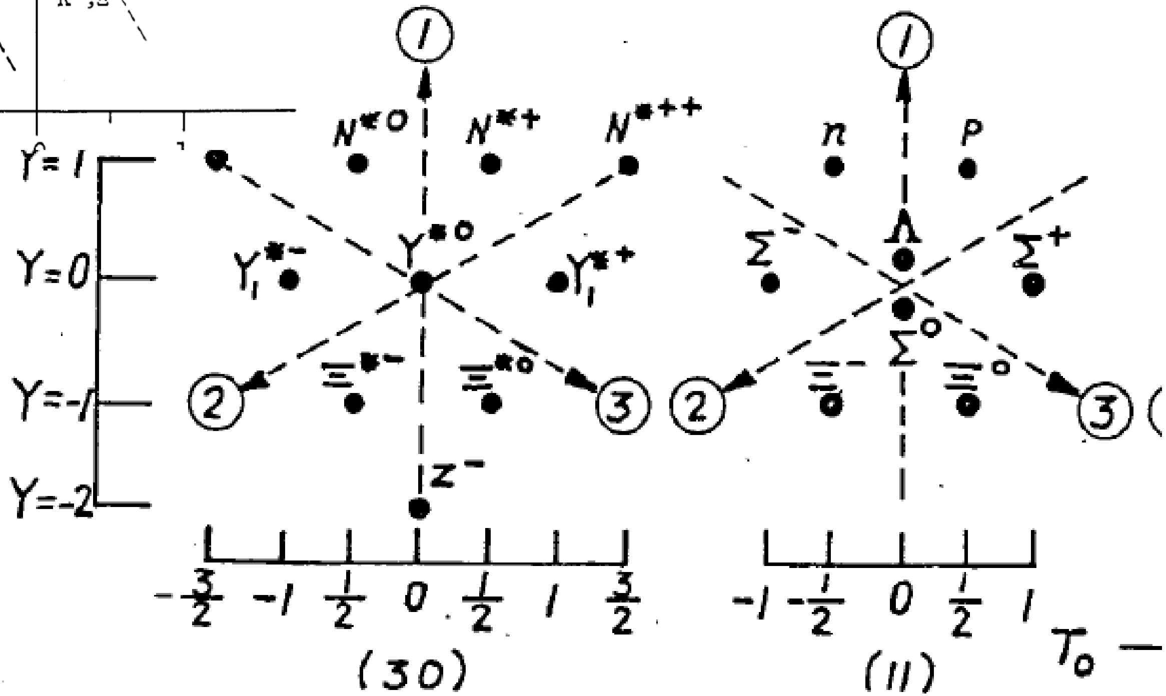
There are a number of ways of introducing new groups [...] Almost any finite or infinite group can provide some discrete quantum number. The physics of the things almost always emerges from a skillful bookkeeping of the correspondence between these basic discrete numbers and observed facts. In the absence of basic physical principles it is quite possible that the correlation of facts and some real numbers can be achieved in more than one way. [if SU(3), why not SU(4), or O_7, or…?].

We must, therefore, seek some guidance from the most basic invariance principles of physics, meaning that any extra quantum degrees of freedom for elementary particles must be based on the inhomogeneous Lorentz group. We must establish a bridge between space-time and unitary structure of micro-physics."

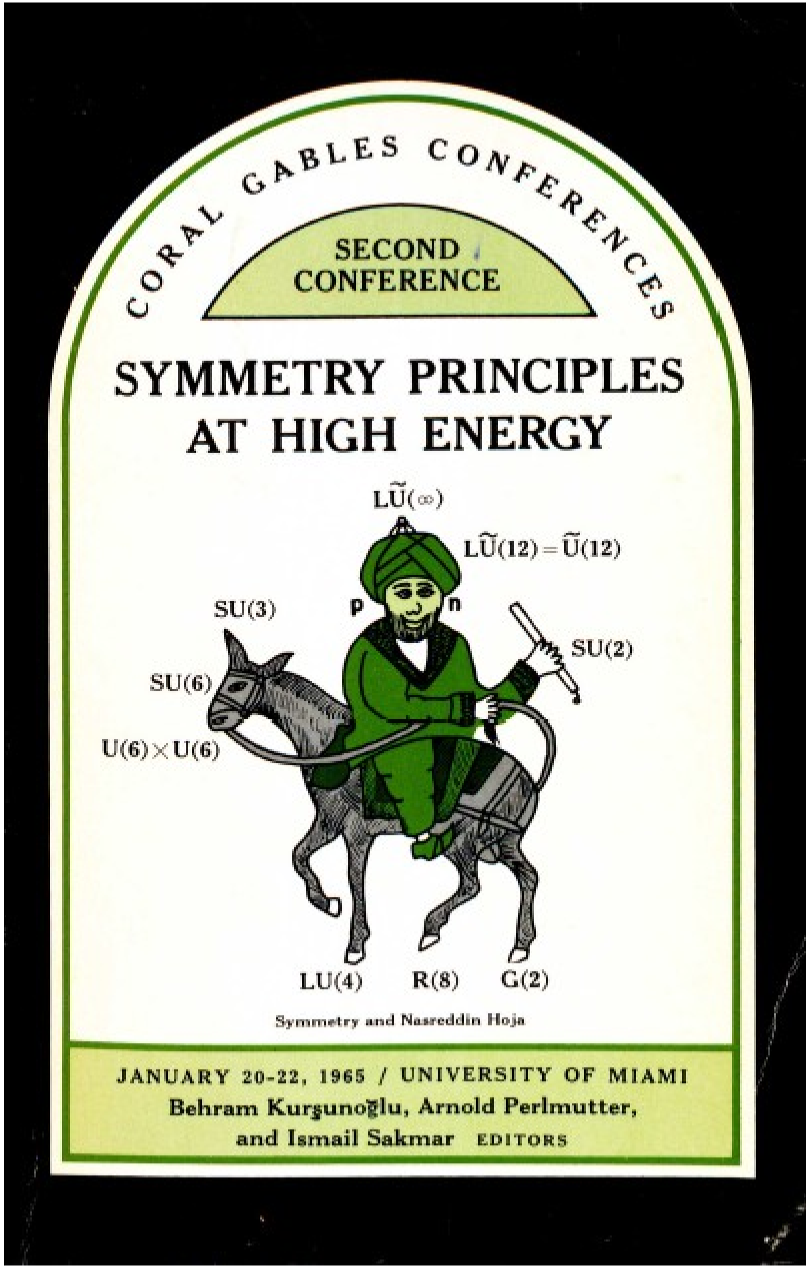
1st proceedings (1964): various diagrams showing the mathematical features of the SU(3) particle classification







Proceedings 2nd conference -
Hoja, SU(3) and its possible extensions!



From the volume's editorial preface:

"The subject of combining internal and space-time symmetries was one of the topics discussed at the First Coral Gables Conference. The issues raised at that time have since been considered by many experts, and their efforts have culminated in the proposal that SU(6) be accepted as a possible symmetry group of hadrons.

At this year's conference, a major part of the discussion was concerned with the extension and development of this proposal, and it was the opinion of the participants that considerable progress was achieved."

Fourth conference (1967) - From Cabibbo’s summary

“After some ambitious attempts to have an intimate merger of internal and Lorentz symmetry, we had the explosive success of nonrelativistic SU(6). The initial attempts to make SU(6) into a completely relativistic scheme were frustrated by a series of beautiful impossibility theorems, the latest version of which was presented here by Professor Coleman.”

Coleman, Proceedings of Conference on "Symmetry Principles and Fundamental Particles" (Istanbul 1967 - also organized by Kursunoglu)

We would have been extremely happy to find a relativistic generalization of SU(6), even if all particles in a supermultiplet had the same mass, and even if there were no good perturbative mass formulas. The remaining lectures will be devoted to explaining why even this modicum of happiness is denied us.

Fifth and last conference (Jan. 1968) - From Cabibbo’s summary:

The concept of symmetry (and symmetry breaking) has been a major tool in the past few years, leading to great advances in the understanding of elementary particle physics. The feeling now is that it has nearly outgrown its usefulness as a tool to be used alone, and that it will more and more merge with more dynamical concepts in further attacks on the problems of elementary particles interactions

From Ne'eman's summary of all five confereces:

I am not only the summarizer of these five conferences but I am also the undertaker responsible for their lying in peace forever. The series of conferences on "Symmetry Principles at High Energy" is hereby closed.

From today's point of view it is difficult to imagine that the impulse for a series of conferences on "symmetry principles at high energy" could have run out precisely a this time - but it was so....

Conclusion:

- Empirically successful models based on SU(2), SU(3), were not regarded as fully satisfactory, as those group structures allegedly lacked physical significance….
- ...group-theoretically refined attempts to expand them into a construct (theory?) based on physically significant group structures had no empirical success
- there was a quite strong emotional commitment of some historical actors towards the possibility of joining internal and space-time symmetry (why? unclear)
- in the 1970s, we see a similar constellation, this time focused on gauge symmetries (GUTs, supersymmetric GUTs, technicolor...) and from these projects today's BSM physics emerged