A Knowledge-based System for Classifying Particle Reaction and Decay Processes

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Abstract

In particle physics conservation laws have been devised to explain allowed and forbidden particle reactions and decays. They can be used to classify particle reactions and decays into strong, electromagnetic, and weak interaction processes. This article describes a computational system, which tests conservation rules to find allowed and forbidden reaction and decay processes, and to classify allowed processes into strong, electromagnetic, and weak interactions.

Keywords: Particle Interactions, Particle Decays, Expert System, Knowledge-based System

1. INTRODUCTION

To date, many hundreds of different particles have been discovered. These can decay in many different ways as listed in [1]. The standard model [2] explains why some particles decay into other. Strong, electromagnetic, and weak interactions all cause these decays. Conservation laws that are summarized in Table 1 [3] the various additive and multiplicative quantum numbers and which interactions conserve them are used to classify the decay. All quantum numbers [2] are conserved in strong interactions (SI). Isospin and G-parity are violated in the electromagnetic interaction (EM). In weak interactions (WI), some of the quantum numbers are violated with some restriction. The largest listing of particles has been compiled by the particle data group (PDG) [4]. To know the interaction type for a given reaction or decay one needs to acquire knowledge of the quantities that can be conserved, check the conservation rules, and thereby determine the interaction type. For non experts this is not an easy task. This process is time consuming as well. A possible solution for this is to use artificial intelligence techniques. In this paper we describe a knowledge-based system, popularly known as an expert system that can be used for this task. While expert systems are not able to think, they do have some advantages over the human expert in terms of consistency in delivering answers and not jumping to conclusions without considering all details. An expert system usually consists of knowledge base and inference engine [5]. The knowledge base itself consists of the knowledge that is specific to the domain of application including facts about the domain, and rules that describe relation in the domain. The inference engine examines the facts and determines whether or not they are satisfied by using the rules in the rule-base. It also determines the order in which these rules are fired. We have developed our knowledge-based system using the CLIPS language [6]. CLIPS supports for rule-based, object-oriented, and procedural programming [7]. The default interface for CLIPS language is command-line interpreter. CLIPS is a rule-based production language. The paper is organized as follows: section 2 describes the knowledge representation and CLIPS rules, section 3 presents the results with a figure, section 4 concludes the paper, and section 5 gives the references.

Conserved Quantity	Interaction (Yes = quantity is conserved)		
	SI	EM	WI
Energy/Momentum	Yes	Yes	Yes
Q – Charge	Yes	Yes	Yes
J - Angular Momentum	Yes	Yes	Yes
L - Lepton number	Yes	Yes	Yes
L_e - Electronic number	Yes	Yes	Yes
L_μ - Muonic number	Yes	Yes	Yes
L_τ -Tauonic number	Yes	Yes	Yes
□ - Baryon number	Yes	Yes	Yes
S - Strangeness	Yes	Yes	No ($\lvert\Delta S\rvert = 0,1$)
C - Charm	Yes	Yes	No ($\lvert\Delta C\rvert = 0,1$)
B - Bottom	Yes	Yes	No ($\lvert\Delta B\rvert = 0,1$)
T - Top	Yes	Yes	No ($\lvert\Delta T\rvert = 0,1$)
I - Isospin	Yes	No	No ($\Delta I = 1$, 1/2)
I_3 - 3rd component	Yes	Yes	No
P – Parity	Yes	Yes	No
C - Charge conjugation	Yes	Yes	No
CP (or T)	Yes	Yes	No (rare violations)
CPT	Yes	Yes	Yes
G – Parity	Yes	No	No

TABLE 1: Summary of conservation rules [3]

2. KNOWLEDGE REPRESENTATION

We used the computer readable data of particle properties as listed in [8] for this work. According to the instructions provided there, particle properties of anti-particles were added to the list. All particle properties and those of their anti-particles were stored in a text file. Some names were changed in order to be readable by CLIPS. For example 'rho(770)' was changed to 'rho[770]'. We converted about 240 particles, and their properties into facts in CLIPS syntax, and stored them in the knowledge base of the CLIPS language. Conservation rules that are shown in Table 1 were written as rules in CLIPS, and stored in a file. The following piece of code shows the structure of a CLIPS facts template. Note that this illustrates the syntax for the CLIPS programming language defined in [5].

```
(deftemplate particle " "
(slot mass (default 0))
(slot width (default 0))
(slot I (default ND))
(slot G (default ND))
(slot J (default 0))
(slot P (default ND))
(slot C (default ND))
(slot A (default 0))
(slot PDG-MC (default 0))
(slot Chrg (default 0))
(slot B (default 0))
(slot name (default "0"))
(slot quarks (default "0"))
(multislot qflavor-qn (default 0 0 0 0))
(multislot LF-qn (default 0 0 0 0))
```

The particle reaction $a + b \rightarrow c + d + e + f$ is added to the fact list at run-time, where a, b, c, d, e , and f represent particle names. The template is as follows

```
(deftemplate reaction " reaction" (multislot lhs (default 0)) (multislot rhs (default 0)))
```

While the left hand side 'lhs' can take one or two arguments, the right hand side 'rhs' can take a maximum of four arguments. A particle reaction or decay is stored as a fact by taking a, b, c, d, e, and f from user input. The rules (knowledge) are used to check conservation rules. A CLIPS rule is something like an "if----then" statement in procedural language, but it is not used in a procedural way. When the "if" parts are satisfied, given only that the rule engine is running. CLIPS rules were written to fire in a specific order. For example, the following CLIPS rule checks the strangeness conservation [9] of a reaction or decay and then takes actions for executing other rule(s).

```
(defrule rule-Strangeness-conservation " checking Strangeness conservation "
?st <- (state (value 1))
?sa <- (conserved (Charge yes)(Mass yes)(Lepton-number yes)(Electronic-number yes)
(Muonic-number yes)(Tauonic-number yes)(Baryon-number yes)(Strangeness no)
(Angular-momentum yes))
(reaction(lhs ?a1 ?a2)(rhs ?b1 ?b2 ?b3 ?b4))
(particle (name ?a1&~"nil")(qflavor-qn ?qa1 $?))
(particle (name ?a2)( qflavor-qn ?qa2 $?))
(particle (name ?b1&~"nil")(qflavor-qn ?qb1 $?))
(particle (name ?b2&~"nil")(qflavor-qn ?qb2 $?))
(particle (name ?b3)(qflavor-qn ?qb3 $?))
(particle (name ?b4)(qflavor-qn ?qb4 $?))
=> (retract ?st)
(bind ?*DeltaStrange* (difference ?qa1 ?qa2 ?qb1 ?qb2 ?qb3 ?qb4))
(if (= ?*DeltaStrange* 0) then
(retract ?sa)
(modify ?sa (Strangeness yes))
(format t "%-25s %5s" "Strangeness" "Yes")
(printout t crlf crlf)
else
(format t "%-25s %1d" "DeltaS" ?*DeltaStrange*)
(printout t crlf crlf) )
(modify ?st (value 2)) )
```

The relationship between 3rd component (I_3) of isospin, electric charge (Q), and hypercharge (Y) $I_3 = Q - Y/2$ [10]was used to calculate I_3. Conservation of I_3 is similar to the conservation of charge, lepton numbers, baryon number, strangeness, charm, beauty, and top. To check the conservation of angular momentum and isospin, which are different from the others, the procedure as mentioned in the note [11] was followed. We did not require checking for G-parity, CP, and CPT conservations. Once the conservation rules were checked, we required additional rules to check for distinguishing allowed and forbidden decays. If a reaction or decay process is allowed, then this expert system gives interaction type; otherwise, it gives a reason for forbidding the process. In SI and EM, charge conjugation and parity are conserved. Parity and charge conjugation conservations were checked to identify forbidden decays. Parity violation decays [12], for example, $\eta^0 \nrightarrow \pi^+ + \pi^-$ and $\eta^0 \nrightarrow \pi^0 + \pi^0$ can be expressed as a single rule $0^- \nrightarrow 0^- + 0^-$ with $J^P = 0^-$ representing the standard convention for labeling a spin and intrinsic parity of a particle. In these, the symbol ($\nrightarrow$) implies that the decay is not allowed. These forms of rules were written, by examining, for parity violating decays which are listed in [1], and implemented as CLIPS rules. Similar forms of rules were written for charge conjugation violating decays as well. As an example, charge conjugation violating decays $\pi^0 \nrightarrow 3\gamma$ and $\omega \nrightarrow 2\gamma$ can be expressed as $0^+ \nrightarrow 1^- + 1^- + 1^-$ and $1^- \nrightarrow 1^- + 1^-$ respectively, where 0^+ and 1^- represent spin and charge conjugation with the notation J^C [12]. The decays $\Lambda^0 \rightarrow \pi^- + p$, $n \rightarrow p + e^- + \overline{\nu_e}$, and $\mu^- \rightarrow e^- + \nu_\mu + \overline{\nu_e}$ represent allowed hadronic, semi-leptonic, and leptonic weak processes respectively. As note [12] selection rules for I_3 and S violation for the above first two decay processes can be written as follows: (i) $|\Delta I_3| = 1/2$, $|\Delta S| = 1$ for hadronic decays (ii) $|\Delta I_3| = 1, |\Delta S| = 0$ for strangeness-saving semi-leptonic decays and $|\Delta I_3| = 1/2$, $|\Delta S| = 1$ for strangeness-changing semi-leptonic decays. In other words, the allowed strangeness-changing semi-leptonic decays are given by the $\Delta S = \Delta Q$ rule [1], where ΔQ is the change of charge of hadrons. Corresponding selection rules [1] for charm and beauty changing decays are $\Delta C = \Delta Q$ and $\Delta B = \Delta Q$ respectively. In the standard model the processes involving $\Delta S = 2$, $\Delta C = 2$, and $\Delta B = 2$ are forbidden in first order weak interactions [1]. Also the flavor changing ($\Delta S = 1$, $\Delta C = 1$, and $\Delta B = 1$) neutral current decays [1] are forbidden. As an example, the strangeness changing decays $K^+ \nrightarrow \pi^+ + \nu_l + \bar{\nu}_l$ is forbidden, where l is either e, μ, or τ . Those rules were written in CLIPS form as well.

3. RESULTS

Comparative tests were done by selecting interaction type known decays and reactions listed in [1]. All the expert system findings are consistent with them. For illustration, some of the decays and reactions are listed in Table 2. The first column of Table 2 shows some of the particle reactions or decays in usual notation. While the second column shows user inputs to the expert system for respective reactions or decays in our particle notation, the third column shows the expert system's finding for them. The detail outputs of this system for the decay $\Lambda^0 \rightarrow \pi^- + p$ and $\Xi^- \rightarrow n + \pi^-$ are shown in Figure 1.

Particle reaction/decay	User input	The expert system output
$\mu^- \rightarrow e^- + \nu_\mu + \overline{\nu_e}$	mu- → e- + nu[mu] + nu[e]bar	leptonic weak interaction
$n \rightarrow p + e^- + \overline{\nu_e}$	n → p + e- + nu[e]bar	semi-leptonic weak interaction
$\Lambda^0 \rightarrow \pi^- + p$	Lambda[P01]0 → pi- + p	hadronic weak interaction
$\Xi^- \rightarrow \Lambda^0 + \pi^-$	Xi[P11]- → Lambda[P01]0 + pi-	hadronic weak interaction
$\Xi^- \rightarrow n + \pi^-$	Xi[P11]- → n + pi-	forbidden, violating ($\Delta S = 0, \pm 1$) rule
$\rho^0 \rightarrow \pi^+ + \pi^-$	rho[770]0 → pi+ + pi-	strong interaction
$K^- + p \rightarrow \Xi^- + K^+$	K- + p → Xi[P11]- + K+	strong interaction
$\Sigma^0 \rightarrow \Lambda^0 + \gamma$	Sigma[P11]0 → Lambda[P01]0 + gamma0	electromagnetic interaction
$\eta^0 \rightarrow \pi^0 + \pi^0$	eta0 → pi0 + pi0	forbidden, (P,CP violating)
$\eta^0 \rightarrow 3\gamma$	eta0 → gamma0 + gamma0 +gamma0	forbidden, (C violating)
$\Sigma^- \rightarrow p + e^- + \overline{\nu_e}$	Sigma[P11]0 → n + e- + nu[e]bar	Strangeness-changing semi-leptonic weak interaction
$K^+ \rightarrow \mu^+ + \nu_\mu$	K+ → mu+ + nu[mu]	Strangeness-changing semi-leptonic weak interaction
$\rho^0 \rightarrow \pi^0 + \pi^0$	rho[770]0 → pi0 + pi0	forbidden, (C violating)
$\pi^- + p \rightarrow K^- + \pi^+ + \Lambda^0$	pi--+p → K- + pi+ + Lambda[P01]0	forbidden, violating ($\Delta S = 0, \pm 1$) rule

TABLE 2: This shows the expert system rule-based decision for given particle reactions and decays.

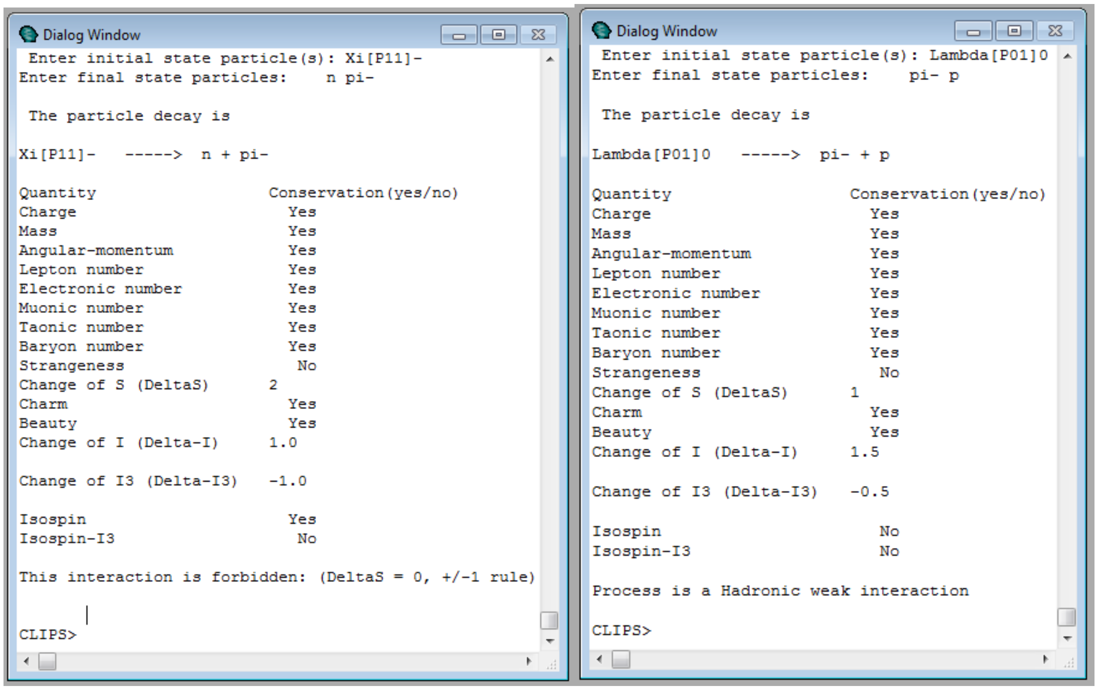

FIGURE 1: Screenshots of the expert system output for $\Xi^- \rightarrow n + \pi^-$ decay (left) and $\Lambda^0 \rightarrow \pi^- + p$ decay (right).

4. CONCLUSION AND FUTURE WORK

The paper we have presented provides the design and development of a proposed knowledge-based system to classify particle reactions and decays into interaction types. Our knowledge-based system is a rule based system, and we used CLIPS language to store our knowledge base. The interface of this system is the CLIPS default interface. This can be integrated with other higher languages to have graphical user interface (GUI). Finally, more importantly, we would like to mention that this system can be extended to find particle decay channels of a decaying particle.

5. REFERENCES

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