# RUNNING NUANCE* **

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This article describes version 3.006 of Nuance, an advanced and freely available neutrino generator written by Dave Casper of University of California, Irvine. Source codes of the program are publicly available. This description is based on Dave Casper's article "The Nuance Neutrino Physics Simulation and the Future", `http://nuint.ps.uci.edu/nuance/files/nuance_nuint01.pdf`, Nuance website at `http://nuint.ps.uci.edu/nuance/`, README.txt file provided in the src folder of Nuance distribution, and my own experience as a Nuance user.

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## 1. Installing

The installation procedure is described on the official Nuance website at `http://nuint.ps.uci.edu/nuance/download.htm`. Installation script available to download on the website installs version 2 of Nuance, but there are also instructions to download the newest version of the package.

## 2. Description

Nuance is a neutrino generator, simulating neutrino interactions with a given medium (like water). The result — a list of particles produced in each interaction, along with other information — is saved to a (text or binary) data file. Transport of particles through the detector materials is not handled (usually you would use GEANT4, FLUKA or other software of that kind for this purpose).

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The simulation procedure is divided into two stages:

- Cross-sections and rate calculation. In this stage the proportions between various interaction channels are determined. It is the most time consuming part of simulation (can take hours if we run Nuance with a complicated beam profile).

- Event generation. This is the simulation of interactions themselves.

The simulation algorithm simulates neutrino interactions in two steps:

- Primary interaction. The primary neutrino–nucleon interaction is simulated (except for coherent interactions, in which the neutrino interacts with a nucleus as a whole, and scattering on electrons).

- Secondary interactions of hadrons in nucleus. Passage of hadrons produced in the primary interaction through nucleus. This stage is usually known as Final State Interactions or intranuclear cascade. It is dependent on the type of nucleus (number of nucleons *etc.*). Processes like pion absorption occur in this stage.

The reaction channels that are simulated in primary vertex are: quasi-elastics (QE), resonant production (RES), deep inelastic scattering (DIS) and other, less significant processes like coherent/diffractive production and elastic scattering on electrons.

More information about the models used in Nuance can be found in Dave Caspers's article mentioned above. Some changes have been implemented since then, many of them in v3 described here. Some modifications for MiniBooNE experiment have also been incorporated, but not in the v3 version.

The default target (medium) is water. However, later in this article we will learn how to specify other target nuclei.

## 3. Running Nuance

### *3.1. Command-line mode*

This is the simplest mode and is most convenient for generating events for a monoenergetic neutrino beam.

```
nuanceMc.exe -mono 14 1000.  -nevt 2000 -h output.hbk !
```

This will generate 2000 events with a monoenergetic, 1 GeV (1000.) beam of muon neutrinos (code 14) and save results into output file (ntuple) output.hbk. A detailed list of command line options can be found in README.txt file.

### *3.2. Card file mode*

For more complicated sets of parameters you can use specialized configuration files with so called cards — commands specifying parameter values. There are many examples of such files in the data directory. To use a card file in a Nuance run simply put the card file's name instead of the exclamation mark at the end of the above example (the two modes can be mixed — you can use both, cards and command-line parameters if you like).
There is a special card file called nuance_defaults.cards which is always read by the program — it defines default configuration of Nuance. Your card files and command line options override these default settings.

These are some of the most useful cards:

- `*DO BEGI`
  every card file starts with this;

- `*FINISH`
  at the end of every file;

- `*DO HIST`
  `'t2k_nd280_hist.hbk'`
  saves generated events to a specified file (like -h on command-line);

- `*DO NEUT`
  `14 -14`
  specifies which neutrino flavors should be considered (muon neutrino and antineutrino in this case — like -n);

- `*DO RATO`
  `'t2k_nd280.fzc'`
  saves calculated rates to a specified file (like -o);

- `*DO RATI`
  `'t2k_nd280_rates.fzc'`
  tells the program to read rates from a file instead of calculating them (like -i);

- `*DO DETE`
  `'SKAL'`
  defines the detector volume (SK full volume here — the volumes are defined in nuance_defaults.cards; like -t);

- `*DO NEVT`
  `500000`
  how many events we would like to generate;

- `*DO PROC`
  `‘CCRS’ ‘NCRS’`
  what channels to consider (CC/NC RES here; like -proc);

- `*DO STAB`
  `310`
  makes the specified particle stable ($K^0$ short in this case). Use PDG particle codes to specify particles;

- `*DO DECA`
  `111`
  forces Nuance to decay specified particle ($\pi^0$ here).

Sometimes it is advisable to split the simulation into two parts — first you run Nuance to calculate rates (which is a time consuming process) and save result to .fzc file (use *DO RATO and do not use *DO NEVT). Then you can generate events with different settings using this .fzc file (using *DO RATI and *DO NEVT).

If you use -nopn switch in the command-line mode, you will turn off final state interactions. This way you will get primary interactions only.

## 4. Paw and Nuance ntuples (hbk files)

Paw is a particle physics' analysis tool, a predecessor of Root. It is a command line application and is not very user friendly, but it is the easiest and the most natural way to get access to Nuance ntuples. However, if you want to use Root, you can — in this case you should convert HBOOK Nuance ntuples to Root file using h2root program distributed with Root. If you are using paw, these are the commands to start with:

- `h/fil 30 name.hbk`
  opens a file;

- `nt/list`
  lists the ntuples (one file can contain several ntuples; Nuance files usually have two);

- `opt stat`
  to show statistics on histograms (like mean, RMS, *etc.*);

- `nt/plot 1.p_neutrino(4)`
  draws a histogram of incoming neutrino energy in ntuple number 1 format: `nt/plot ntuple_number.variable_name`;

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  draws a histogram of incoming neutrino energy in ntuple number 1
  format: `nt/plot ntuple_number.variable_name`;

- `h/create/1d 100 'nu momentum' 50 0.  1000.`
  `nt/project 100 1.p_neutrino(4)`
  to have the plot the way you like (here: 50 bins, from 0. to 1000. MeV) you have to create the histogram yourself first (giving it a number and a name) and then fill it with data ('project');

- `nt/loop 1 funct.f`
  to run funct.f fortran script (this should have a name "funct.f" on disk and contain "funct" function — you usually create such file using `uwfunc` command) on ntuple number 1;

- `help command`
  to get some help on 'command'.

## 5. Nuance ntuple output (hbk files)

Every hbk file contains two ntuples:

- 100 — with cross-section information,

- 1 — with generated events.

I will describe here the event ntuple. The following are the most important ntuple variables (the extended version of this list is available on the nuance website). Particles are numbered according to PDG code scheme.
**cc:** (logical) True if the reaction is charged-current, false if neutral current.
**neutrino:** Particle code of the neutrino.
**target:** Particle code of the target. Particle codes beginning with 41 are used for nuclei (coherent reactions).
**channel:** The reaction code of the event (QE 1-2, RES 3-90, DIS 91-92, for others see README.txt file in Nuance distribution).
**p_neutrino(4):** 4-momentum of the incoming neutrino.
**p_targ(5):** 5-momentum of the target. The 5-th component is 3-momentum magnitude.
**n_leptons:** Number of final-state particles in the leptonic system. Will be one unless a tau-neutrino is involved.
**lepton(n_leptons):** Particle identity for each of the particles in the leptonic system.
**p_lepton(5,n_leptons):** 5-momentum for each particle in the hadronic system.

**n_hadrons:** Number of final state particles in the hadronic system (after final state interactions).
**hadron(n_hadrons):** Particle identity for each of the particles in the hadronic system.
**p_hadron(5,n_hadrons):** 5-momentum for each particle in the hadronic system.

The most important structures are the ones that contain information about particles produced in the interaction. Nuance saves this info in two separate arrays — one for particles produced in the lepton vertex (p_lepton) and one for particles produced in the hadron vertex (p_hadron).

Number of particles in each vertex can be read from hadron and lepton variables. Number of particles in the lepton vertex is usually one — charged lepton for charged current and neutrino for neutral current interactions.

## 6. Nuance plain-text output (kin files)

Nuance can also save event info into text files. To obtain this kind of file, simply specify -k <filename> in the command line mode or use DO TRAC <filename> in the cards file. It can be useful if you want to get access to intermediate states that are produced in the interaction — this information is not available in hbk ntuples. The thing you should look at is the code at the end of each line starting with a `track` word. $-1$ denotes incoming particles, 0 — final states, $-2$ is reserved for intermediate states. You can use it to look at the resonances produced in the resonant channel.

More information about this format can be found on the Nuance website.

## 7. Specifying your own detector materials

To define a new target you have to define atoms/elements (DO ATOM), then material (compound, DO MATE), and then the detector geometry and what materials you put into it (DO TARG). This requires modifying nuance_defaults.cards file. You can add any material you like. However, you have to remember that the model of final state interactions used in Nuance is optimized for water, and that it may be not good enough for other nuclei. MiniBooNE Collaboration have made some significant modifications to the FSI model (they are mainly using carbon as a target) in their version of Nuance to achieve better agreement with MiniBooNE data.

## REFERENCES

[1] D. Casper, The Nuance neutrino physics simulation and the future, `http://nuint.ps.uci.edu/nuance/files/nuance_nuint01.pdf`

[2] Nuance website at `http://nuint.ps.uci.edu/nuance/`

[3] README.txt file provided in the src folder of Nuance distribution.