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# Uncertain<T>: Abstraction Technique for Programming with Uncertain Data

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# General Idea

**Rapid growth in computing powers enabled to shift programmers towards problems with uncertainty.**

- Reading data from sensors.
- Approximation of calculations.

# General Idea (contd..)

**Existing programming languages use simple discrete types (integers, floats or booleans) to represent uncertainty in results.**

**This causes several bugs.**

- Random errors by treating estimates as facts.
- Compounded error through computations.
- False positives and negatives by asking the wrong questions.

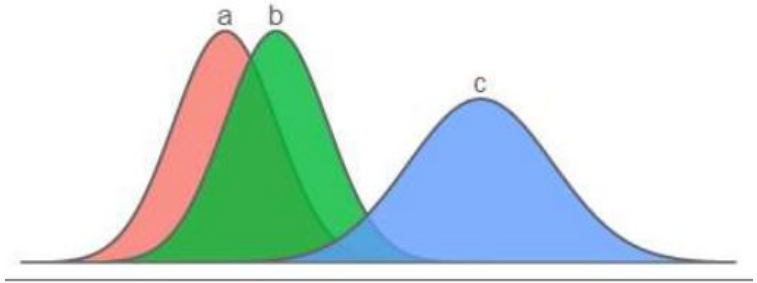
**Existing approaches to handle uncertainty in calculations require experience in probabilistic programming.**

# Uncertain<T>: First-Order Type

**Uncertain<T> is a generic data type that enable to encapsulate and manipulate distributions.**

**Overloads  a variety of operators to enable handling these distributions easily.**

**Example with adding two gaussian distributions.**



# Uncertain<T>: First-Order Type

```cpp
#include <iostream>
#include "Uncertain_t.h"


int main(){

    Uncertain<double>* A = new Gaussian(5,0);
    Uncertain<double>* B = new Gaussian(3,0);

    Uncertain<double>* C = *A + *B;

    std::cout << (*C >= 7.0 && *C <= 9.0) << endl;

    return 0;
}
```

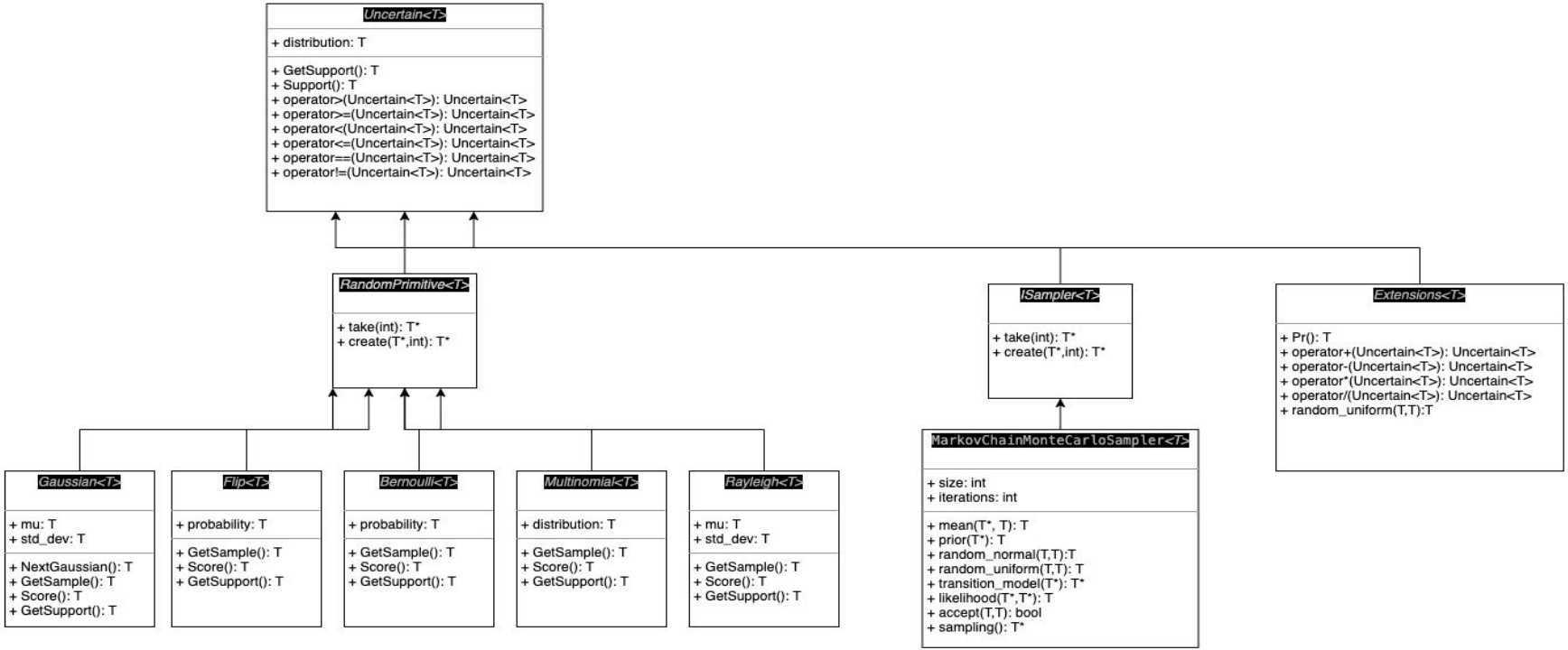
# Uncertain<T>: First-Order Type

```
import UncertainPythonSDP
from UncertainPythonSDP.Uncertain.Gaussian import Gaussian
from UncertainPythonSDP.Uncertain.Uncertaint import Operator

distribution_1 = Gaussian(1.0,2.0)
distribution_2 = Gaussian(2.0,4.0)

sum_distribution = Operator(distribution_1)+Operator(distribution_2)
```

# Design


Uncertain<T>
+ distribution: T
+ GetSupport(): T
+ Support(): T
+ operator>(Uncertain<T>): Uncertain<T>
+ operator>=(Uncertain<T>): Uncertain<T>
+ operator<(Uncertain<T>): Uncertain<T>
+ operator<=(Uncertain<T>): Uncertain<T>
+ operator==(Uncertain<T>): Uncertain<T>
+ operator!=(Uncertain<T>): Uncertain<T>
RandomPrimitive<T>
+ take(int): T*
+ create(T*,int): T*
ISampler<T>
+ take(int): T*
+ create(T*,int): T*
Extensions<T>
+ Pr(): T
+ operator+(Uncertain<T>): Uncertain<T>
+ operator-(Uncertain<T>): Uncertain<T>
+ operator*(Uncertain<T>): Uncertain<T>
+ operator/(Uncertain<T>): Uncertain<T>
+ random_uniform(T,T):T
Gaussian<T>
+ mu: T
+ std_dev: T
+ NextGaussian(): T
+ GetSample(): T
+ Score(): T
+ GetSupport(): T
Flip<T>
+ probability: T
+ GetSample(): T
+ Score(): T
+ GetSupport(): T
Bernoulli<T>
+ probability: T
+ GetSample(): T
+ Score(): T
+ GetSupport(): T
Multinomial<T>
+ distribution: T
+ GetSample(): T
+ Score(): T
+ GetSupport(): T
Rayleigh<T>
+ mu: T
+ std_dev: T
+ GetSample(): T
+ Score(): T
+ GetSupport(): T
MarkovChainMonteCarloSampler<T>
+ size: int
+ iterations: int
+ mean(T*, T): T
+ prior(T*): T
+ random_normal(T,T):T
+ random_uniform(T,T): T
+ transition_model(T*): T*
+ likelihood(T*,T*): T
+ accept(T,T): bool
+ sampling(): T*

# Case Study: Conway's Game of Life

- **The game**
  - Considers world to be an infinite 2 dimensional grid.
  - The 2D grid consist of cells.
  - A cell is either alive or dead.
  - The status of a cell depends on the status of its neighbouring cell.
- **Rules**
  - A live cell with fewer than two live neighbours dies. (Underpopulation)
  - A live cell with two or three live neighbours lives.
  - A live cell with more than three live neighbours dies (Overpopulation)
  - A dead cell with exactly three live neighbours becomes alive (Reproduction)
- **Significance**
  - Generates interesting patterns

Generated patterns

# Case Study: Conway's Game of Life

Ideal pattern

Pattern with a noisy sensor

Pattern with a noisy sensor and Uncertain<T> data type

# Implementation

**Design decisions:**

- Software development approach: Agile
- Programming paradigm : Object Oriented Programming
- Python coding convention : PEP 8
- C++ coding convention : General Best Practices

**System setup:**

- Ubuntu 14.0.4 and above
- Windows 7 and above
- Processor intel i3 and above (recommended)
- Python 2.7 and above
- C++ 11 and above

**Dependencies:**

The tools and libraries used while porting the Uncertain <T>  library to python were:

- Python version: .2.7,3.x
- numpy version: 1.18.x
- scipy version: 1.4.x
- pytest: 6.2.2
- Catch2 for testing.

# Testing

**Unit tests: (Sampling from Gaussian, calculating distribution parameters, logical operations).**

**Continuous Integration Tests**

- **Github Actions**

**Link to repo: Uncertain<T>_python**

**Link to repo: Uncertain<T>_cpp**

```
(base) dadi_vardhan@ubuntu20:~/Downloads/SDP/GUI Repo/SDP_Assignments/Uncertain_T/Uncer
tain_python$ pytest -v -W ignore
============================= test session starts ==============================
platform linux -- Python 3.8.5, pytest-6.2.2, py-1.10.0, pluggy-0.13.1 -- /home/dadi_va
rdhan/anaconda3/bin/python
cachedir: .pytest_cache
rootdir: /home/dadi_vardhan/Downloads/SDP/GUI Repo/SDP_Assignments/Uncertain_T/Uncertai
n_python
collected 6 items

UncertainTests/test_GaussainTests.py::test_gaussian_sample PASSED                [ 16%]
UncertainTests/test_GaussainTests.py::test_gaussian_mean PASSED                  [ 33%]
UncertainTests/test_GaussainTests.py::test_gaussian_bnn_sample PASSED            [ 50%]
UncertainTests/test_GaussainTests.py::test_gaussian_bnn_mean PASSED              [ 66%]
UncertainTests/test_GaussainTests.py::test_gaussian_bernoulli_mean PASSED        [ 83%]
UncertainTests/test_GaussainTests.py::test_gaussian_bernoulli_conditional PASSED [100%]

============================== 6 passed in 12.36s ==============================
```

# Capabilities

- Ability to handle arithmetic and logical operations on several distributions.
- Ability to generate random samples given a distribution’s type and parameters.
- A generic data type that works with integers, floats and doubles.

# Future Work

- Implementation of other distributions. [Python/C++]
- Proving the remaining case studies.
- Implement Uncertain<T> on high dimensional data types (e.g arrays).

# Problems Faced

- Existing c# library is not well commented.
- Implementing this library requires deeper understanding of different probabilistic methods.

# Lessons Learnt

- Software development cycle.
- Continuous integration and testing.
- Writing test cases.
- Version control and git.
- Software packaging and distributing.

# Thank You