Project Planning Under Temporal Uncertainty

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Project Planning

- **Project schedule vital for SW developers**
  - Calculate costs, meet project deadlines
- **Support by present-day PM tools?**
  - Highlighting off-schedule project threads
  - “Please provide adequate buffer times”
- **AI planning offers effective support during project definition**
  - Adequate formalism for capturing procedures and supporting abstract action specification
  - Reasoning about uncertainty

HTN Formalism

- **STRIPS-like operator instances as primitive tasks**
- **Abstract actions represented by complex tasks**
- **Methods implement complex tasks by task networks**

$$o = (\mathrm{prec}(o), \mathrm{add}(o), \mathrm{del}(o))$$

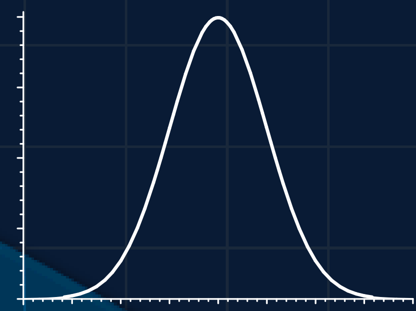
$$d = (T, \prec, V)$$

$$m = (t, (T_t, \prec_t, V_t))$$

$$\begin{aligned}
T' &= (T \setminus t) \cup T_t \\
\prec' &= (\prec \setminus \prec_\delta) \cup \prec_t \cup \\
&\quad \{(t_a, t_t) \mid (t_a, t) \in \prec, t_t \in T_t\} \cup \\
&\quad \{(t_t, t_a) \mid (t, t_a) \in \prec, t_t \in T_t\} \\
V' &= V \cup V_t
\end{aligned}$$

Stochastics

$$rv(o) = \mathcal{X}_{\mathcal{N}(\mu,\sigma^2)}$$



$$D_{\mathcal{X}^1_{D_1}+\mathcal{X}^2_{D_2}}(t) := \int_{-\infty}^{+\infty} D_1(\tau)D_2(t-\tau)d\tau$$

$$\mathcal{X}^i \sim \mathcal{N}(\mu_i, \sigma_i^2) :$$

$$\sum_i \mathcal{X}^i \sim \mathcal{N}\left(\sum_i \mu_i, \sum_i \sigma_i^2\right)$$

- **Continuous random variable**
  - Duration of operator
  - Convolution for operator sequences
- **Normal distribution**
  - Convolution computation
  - Can approximate most stochastic processes

Stochastics

convoluted path duration

$$Pr[\mathcal{I} + \mathcal{Y}^i \geq 0]$$

initial time bound

$$Pr[\mathcal{X}_{\mathcal{N}(\mu,\sigma^2)} < a]$$

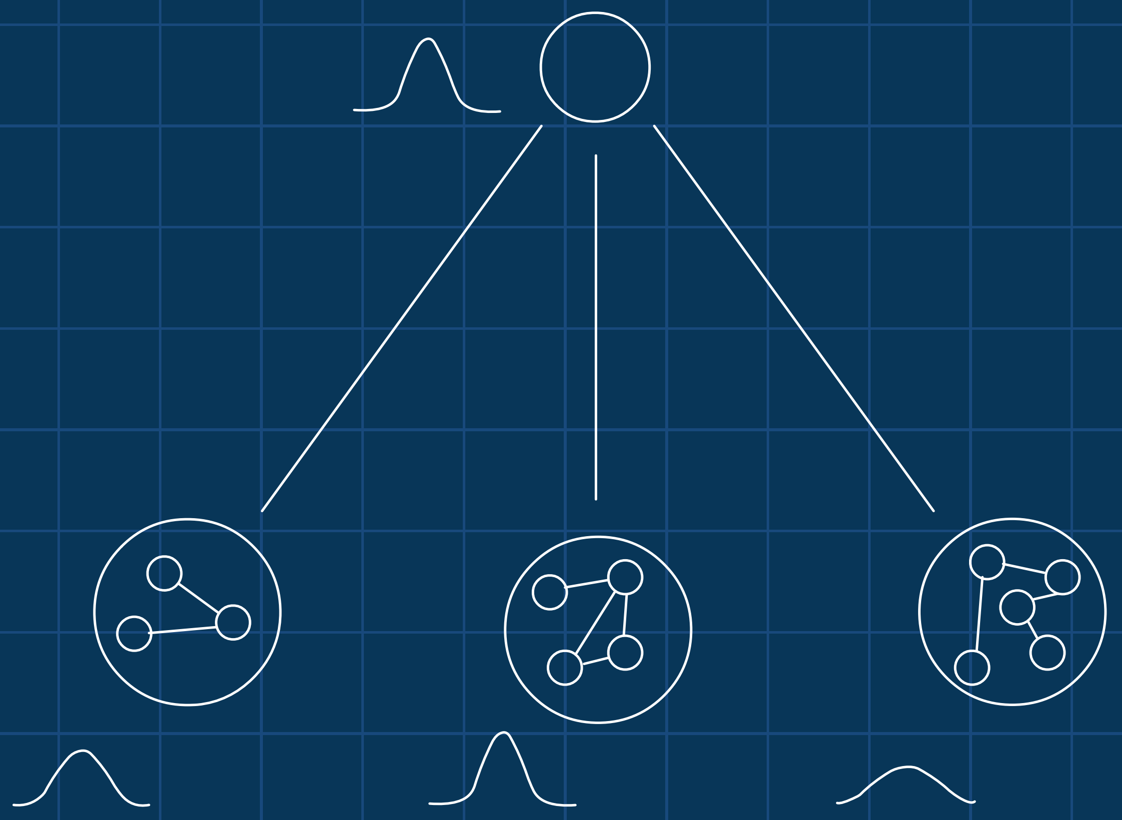
$$:= \int_{-\infty}^{a} \mathcal{N}(\mu, \sigma^2) dx$$

$$= \int_{-\infty}^{a} \frac{1}{\sqrt{2\sigma^2\pi}} e^{-\frac{(x-\mu)^2}{\sigma^2}} dx$$

- **Probability of success**
  - Convolute path operators
  - Approximate anti-derivate
- **Critical Path: minimal probability of success**

Propagating Durations

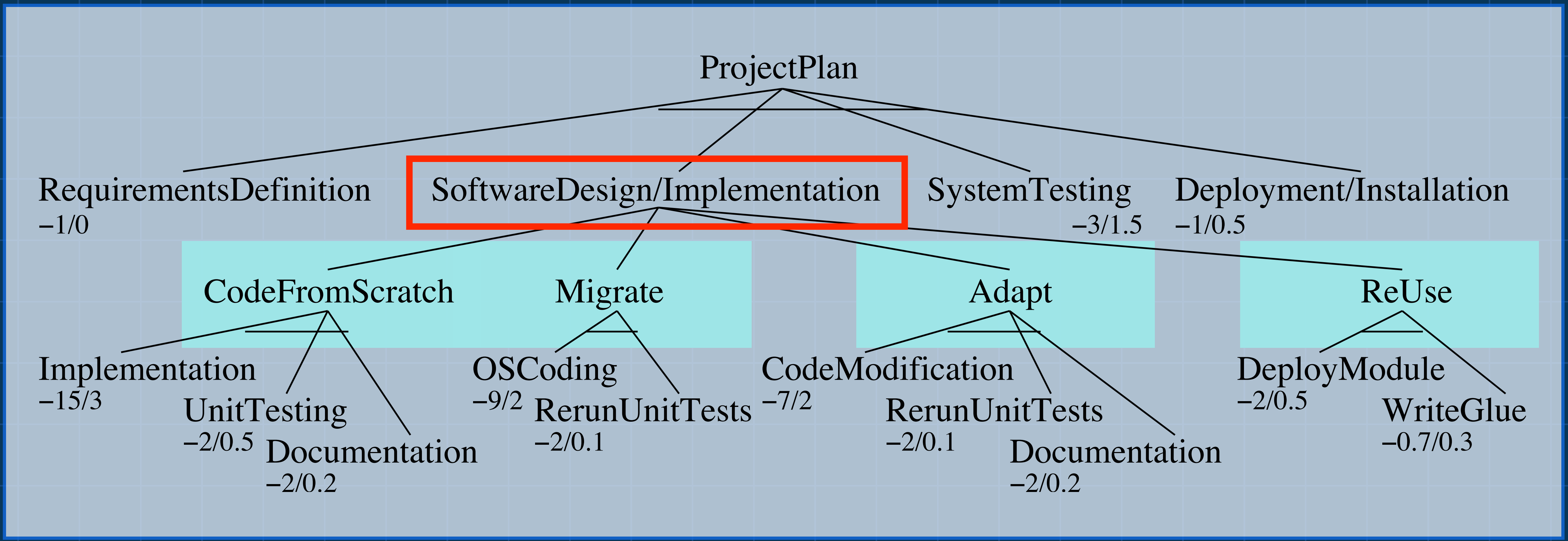
- **Preprocessing Phase**
  - Compute underestimating distributions for paths in primitive task networks
  - Propagate into abstract tasks
  - Compute distributions for processed networks, etc.
- **Heuristic for Task Expansion**



$$\min\left(\mathcal{X}_{\mathcal{N}(\mu_i,\sigma_i^2)}\right) := \mathcal{Y}_{\mathcal{N}\left(-\min_i(|\mu_i|),\min_i(\sigma_i^2)\right)}$$

Example

-2.7/0.8 **Underestimation for SD/I**



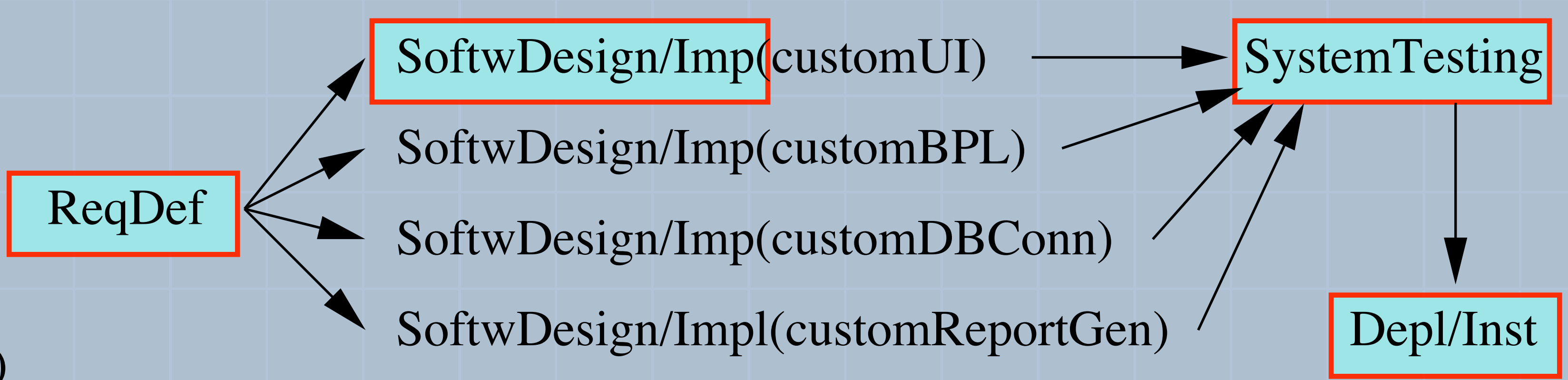
-19/3.7 -11/2.1 -11/2.3 -2.7/0.8

Propagated duration

Example

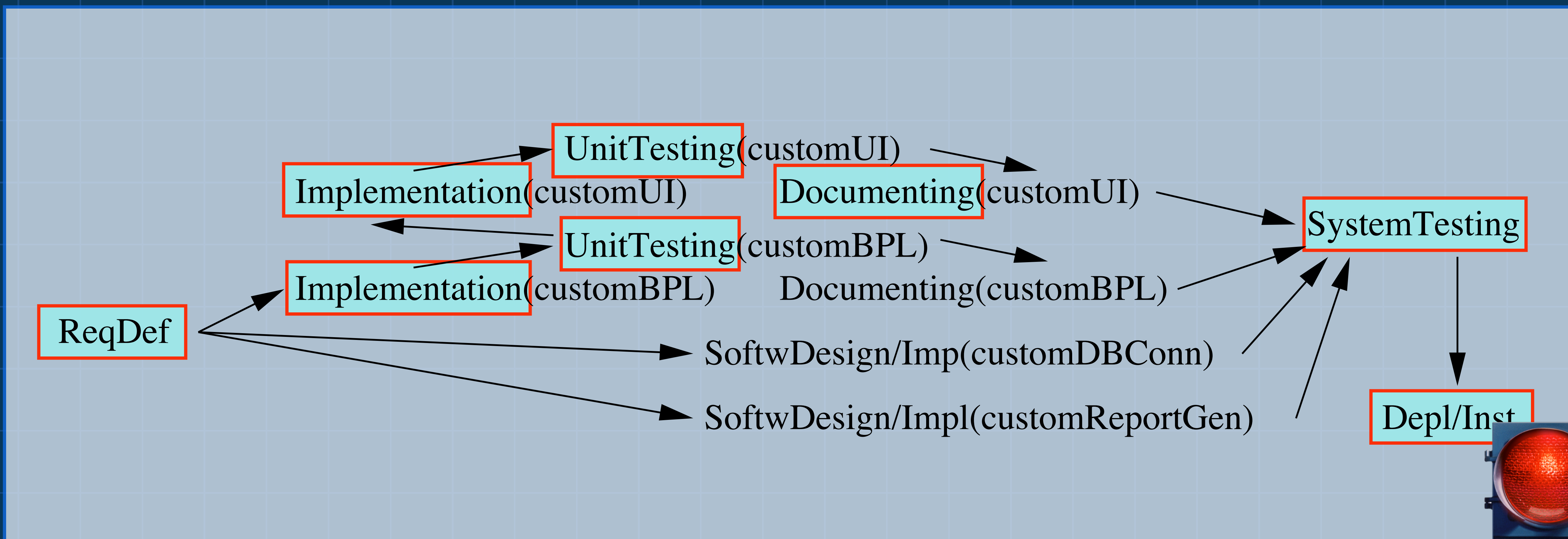
Project deadline is 36 days, acceptable prob. of success is 85%

in–Repository(RepGen–16004)
OS(customUI, Linux)
OS(customBPL, Linux)
OS(UI–2705, Win)
OS(DBC–Orcl–5, Sol)
matches(func–req–A, DBC–Orcl–5)
interfaces(customUI, customBPL) . . .



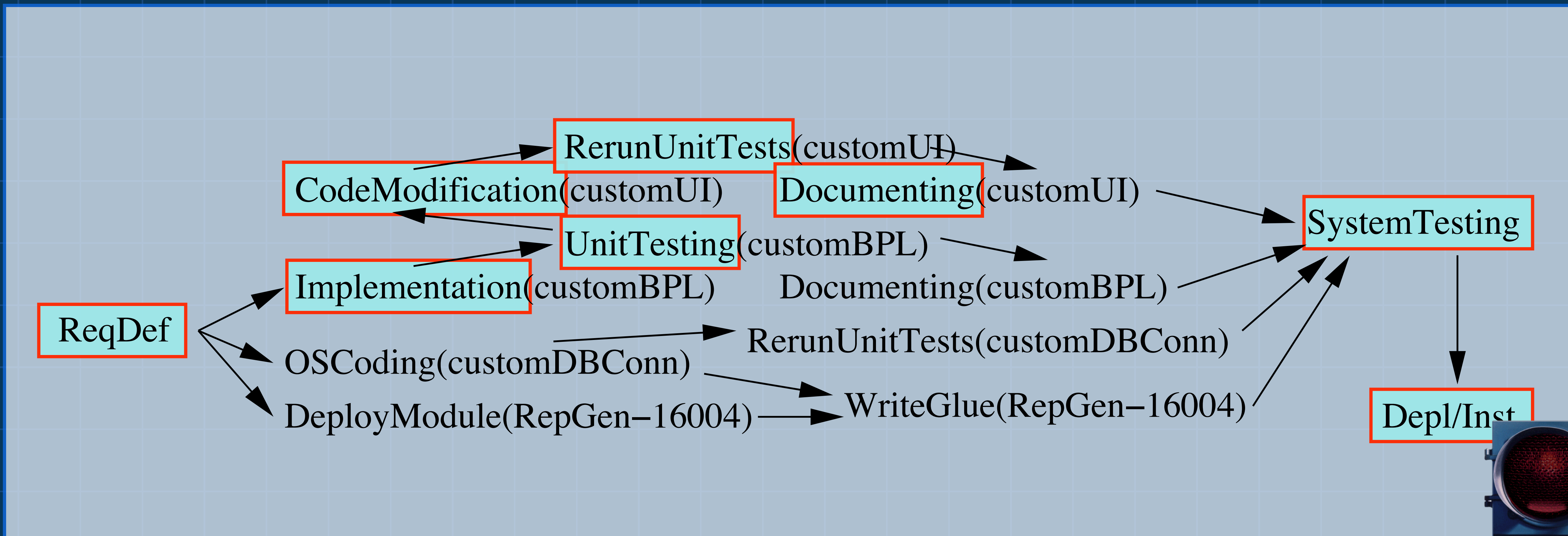
$$Pr[\mathcal{Z}_{\mathcal{N}(28.3,2.8)} \geq 0] = Pr[\mathcal{I}_{\mathcal{N}(36,0)} + \mathcal{Y}^{1}_{\mathcal{N}(-7.7,2.8)} \geq 0] \approx 100\%$$

Example

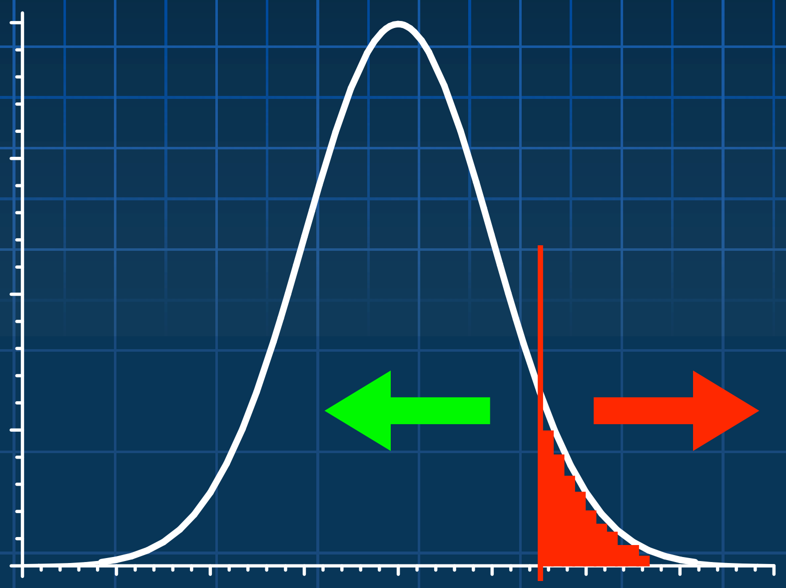


$$Pr[\mathcal{Z}_{\mathcal{N}(-5,9.2)} \geq 0] = Pr[\mathcal{I}_{\mathcal{N}(36,0)} + \mathcal{Y}^{1}_{\mathcal{N}(-41,9.2)} \geq 0] \approx 4.96\%$$

Example



$$Pr[\mathcal{Z}_{\mathcal{N}(7,7.8)} \geq 0] = Pr[\mathcal{I}_{\mathcal{N}(36,0)} + \mathcal{Y}^1_{\mathcal{N}(-29,7.8)} \geq 0] \approx 85.86\%$$



Conclusion

- HTN Planning with probabilistic action durations and resource consumption for risky scenarios
- Propagation of distribution under-estimations for cutting futile expansions
- Implemented in a multi-agent based planning framework