The Interdependent Networked COmmunity Resilience Modeling Environment

Prepared by John W. van de Lindt & Jong Sung Lee; March 19, 2021
Full list of IN-CORE contributors at: http://resilience.colostate.edu/researchers.shtml

Executive Summary

The primary goal of the NIST Center of Excellence for Risk-Based Community Resilience Planning is to advance community resilience measurement science by creating a decision support system that facilitates community planning and the adoption of best practices that promote community resilience. This decision support system is embedded in a state-of-the-art computational environment (IN-CORE) that integrates physics-based modeling of buildings and other infrastructure, networks for transportation, energy, and water exposed to a spectrum of hazards and hazard intensities, data-based models of socio-economic networks, and resilience-based performance criteria and metrics. This four-page primer gives an overview of capabilities, development progress, and the platform architecture.

Introduction

IN-CORE is intended for several types of users, specifically: *Researchers* that are coding and developing algorithms and can/may contribute back to the source code; *Community Planners* that may opt to use IN-CORE through a web interface with default data sets and set data formats; and *Consultants* such as catastrophe modelers or other resilience analysts. IN-CORE's web interface is under development but v2.0.0 of IN-CORE itself is available at the web sites listed below.

Overview of Platform Architecture

IN-CORE is built on a Kubernetes cluster with Docker container technology. On the cluster, customized JupyterHub, python library of scientific analyses, web services, and light-weight web applications are implemented. There are two main parts to the cluster: 1) IN-CORE web services and web applications, and 2) IN-CORE Lab. The first part is implemented using a SOA pattern of microservices (RESTful web services), API gateway, and lightweight web applications. The second part is a JupyterHub which serves customized JupyterLab (called IN-CORE Lab) with the Python library for IN-CORE (called pyIncore) installed, and other common Python libraries (modules). This is shown in Fig 1.

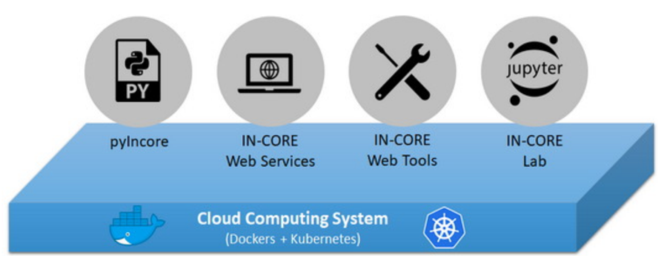

Fig 1. Overview of IN-CORE Architecture

One of the benefits of the design of the platform is that users can chain together pyIncore analyses to create workflows in Python script or chain existing analyses. For example, if a user wants to estimate population dislocation due to a scenario earthquake, then they will need both the population dislocation analysis and building damage from a building damage analysis based on the simulated earthquake. Each analysis contains a specification so the correct inputs are specified before the analysis runs in order to make sure that the output satisfies the input of the analysis being chained with it.

All work is stored as Jupyter notebooks which allows other users to reproduce the analysis and the notebooks can be assigned DOI's for reference in publications. In addition, users can add explanations with text, images, and equations along with Python code in the Jupyter notebook. The notebooks can be shared with others. For example, research notebooks on Joplin (tornado), Galveston (hurricane), and Seaside (earthquake-tsunami) testbeds available online at https://incore.ncsa.illinois.edu/doc/incore/notebooks.html.

The open source for IN-CORE is available at https://github.com/IN-CORE. The source code is under the Mozilla Public License 2.0. The IN-CORE user's manual is accessible at https://incore.ncsa.illinois.edu/doc/incore/index.html.

Overview of unique features, conceptual structure, data structure, and requirements

Figure 1 provides an overview of the scientific structure of IN-CORE. While some of the work to implement the optimizations and visualizations is on-going, v2.0.0 enables users to code their own algorithms or download any of the example notebooks to try it out. IN-CORE is a computational environment that provides analysis, on-line computing resources, data management for hazards, populations, infrastructure, and community economics. It has building- and household-level resolution to enable integration with infrastructure and social science algorithms for cross-disciplinary dependencies.

- The household models are enabled through synthetic population allocation which de-aggregates census block information to household level by spatially maintaining statistical consistency with census blocks. Specifically, the advanced social science and socio-economic algorithms to predict household dislocation, household relocation algorithms based directly on field study research (Hurricane Andrew, Hurricane Ike, Lumberton Field Studies).

- Models for buildings and networked infrastructure can be user defined. Current models address dependencies and evaluate functionality based on a probability of exceeding a damage state and lack of utility/network services. This can also link to population dislocation and the advanced economic models to effect economic metrics such as household income and tax revenue. Water networks and electrical power networks are modeled at the component level thereby providing linkage to household dislocation or other models.

- Economic models (for current testbeds) are available as computable general equilibrium (CGE) models which are geospatially linked with physical infrastructure systems and assess impacts on community level economics (tax base, household income, etc).

- Flood analysis in IN-CORE utilizes fragilities rather than depth to damage functions, thereby enabling propagation of uncertainty. The first suite of fragility models for buildings subjected to flood are available in IN-CORE, and either a tier 1 or tier 2 flood hazard analysis can be combined with this suite of building archetypes. The most comprehensive longitudinal flood field study to date (https://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.1230.pdf) is driving the social science/population models for flood.

- Finally, IN-CORE enables users the ability to timestep rather than using trajectories. This is necessary to consider the effects of policy changes at key points in time during a recovery simulation such as implementing a policy to relax permitting for residential structures to reduce delay times prior to the construction phase.

Several new features will be added to the next release, v2.5.0 in Aug 2021:

- A policy portfolio, including building codes, land use controls, land acquisition, intervention policies such as structural retrofits to buildings and critical infrastructure (e.g., power, water, gas, transportation system), and user-defined options to reflect a community's characteristics and examine "what if" scenarios.

- Allocation of limited resources (budget, labor, etc.) for mitigation and recovery efforts to meet one or more objectives (e.g., minimize economic loss, minimize population dislocation, maximize building functionality, etc.) subject to community-defined constraints (money, labor, time, zoning requirements, etc.). Multiple objectives can be considered simultaneously to provide an array of solutions to meet a wide spectrum of community-specific goals and priorities. Quantifies the decision tradeoffs and return on investment.

- Decision-support for different levels of granularity (e.g., building-level, block level, census tract level, etc.) according to the availability of data. Although users can use any metrics in their analyses, a set of core resilience metrics that fit community-specific goals and community-defined decision weights will be included for user exploration.

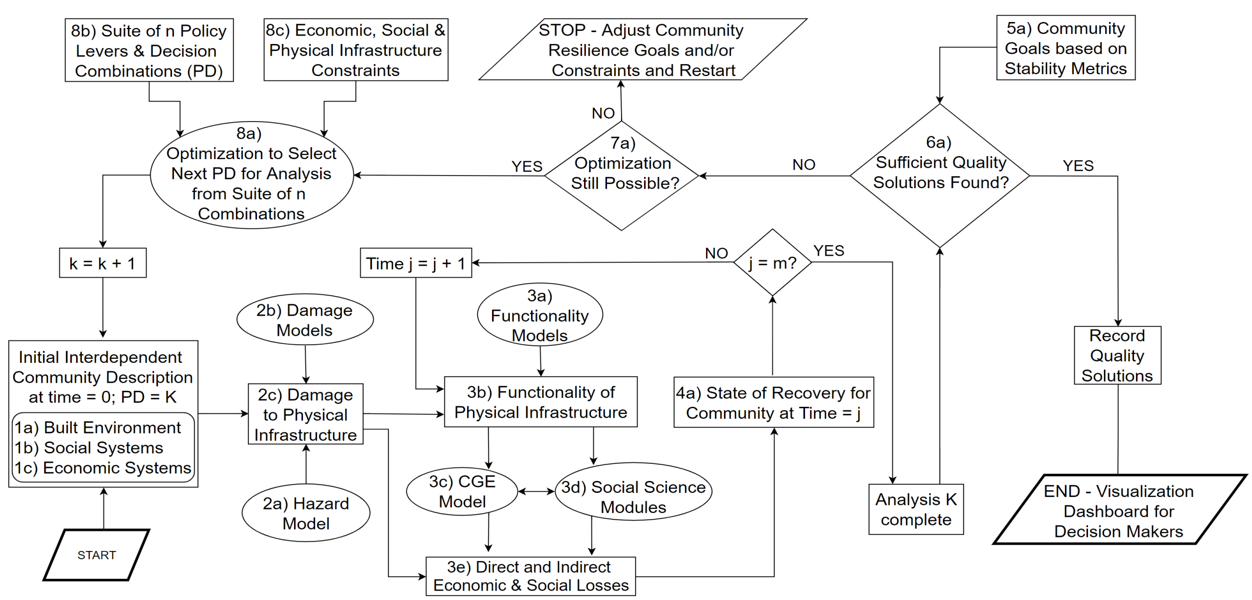

Fig 2. Conceptual scientific structure of IN-CORE

Data in IN-CORE

Three web services in IN-CORE manage and serve the data: 1) Hazard service, 2) DFR3 (Damage, Functionality, Repair, Recovery, Restoration) service, and 3) Data service. The hazard service can store and serve datasets with intensity measures (e.g., Peak Ground Acceleration (earthquake), Maximum inundation depth (Tsunami, flood), EF Rating (Tornado), etc.) in geospatial raster (e.g., geotiff) or vector (e.g., ESRI shapefile) format backed by the Data service. The DFR3 service can store and serve various curves/functions related to Damage, Functionality, Repair, Recovery and Restoration. The Data service can store and serve other types of datasets used for IN-CORE analyses as input data. It includes built-in infrastructure inventory data, census data, economic data, etc. in various formats (e.g., CSV, geotiff, ESRI shapefile, JSON, etc.). Note that due to the chaining of analyses, datasets may be connecting among analyses. In other words, an output dataset of an analysis becomes an input dataset of another analysis.

Data in IN-CORE has metadata with specs for hazards, DFR3 curves, and datasets. For example, the metadata for fragilities contain information on demand types and units, curve types, infrastructure types, etc. The metadata for hazards describes the hazard type (e.g., earthquake, tsunami, tornado, flood, hurricane wave/surge, hurricane wind, etc.), supporting demand types (e.g., PGA, Maximum Inundation Depth, Maximum moment flux, Maximum Wind Speed, etc.). The dataset has general metadata along with dataset type and the name of the schema. Currently IN-CORE has adopted the W3C CSVW tabular data specification to express the dataset type schema. The metadata is in JSON format and the semantics service to serve dataset types is in-progress.

Each service has an access control mechanism by Space (like a workspace), and each user has their own private space that is only accessible by the owner. There are two public Spaces, "incore", and "ergo", that anybody who has account on IN-CORE can access. The "ergo" space contains data from the Ergo/MAEViz repository which was collected by Mid-American Earthquake Center and the Ergo consortium. The "incore" space contains data developed and collected by the CoE and NIST over the last six years. The public spaces are managed by the IN-CORE development team at NCSA with data management process.

Currently, IN-CORE provides ~400 datasets (60% of them are hazard data) with ~180 dataset types, ~1100 fragility curves, 17 earthquake hazards, 3 tornado hazards, 12 tsunami hazards, 2 hurricane wave/surge hazards in the public spaces.

Illustrative example with links

Testbeds, hindcasts and field studies are an essential part of the development and testing of the community resilience assessment algorithms in the IN-CORE computational environment. This approach has required interdisciplinary collaborations involving teams of engineers, social and economic scientists, and information technologists, along with advanced methods for integrating temporal and spatial modeling of community resilience. Each Center testbed, hindcast and field study serves a unique purpose and ensures that IN-CORE is relevant to real communities. Testbeds developed over the last five years include the *Centerville Virtual Community Testbed*, the *Seaside, Oregon Testbed*, the *Memphis Metropolitan Statistical Area (MMSA)*, and the *Galveston/Bolivar Peninsula, Texas Testbed*. The *Joplin, MO Hindcast* was designed to validate the accuracy of IN-CORE in modeling coupled physical, social and economic sectors in responding to the severe Enhanced Fujita-5 tornado of May 22, 2011. Three examples of Jupyter notebooks for these testbeds can be found at:
https://incore.ncsa.illinois.edu/doc/incore/notebooks.html

Some additional IN-CORE resources are located at:
Center of Excellence IN-CORE page: http://resilience.colostate.edu/in_core/
IN-CORE download page: https://incore.ncsa.illinois.edu
IN-CORE Web tools: https://incore.ncsa.illinois.edu/doc/incore/webtools.html
Technical paper and reports: http://resilience.colostate.edu/publications.shtml
The next full release is v2.5.0 scheduled for August, 2021.

Closure, Acknowledgments, and References

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