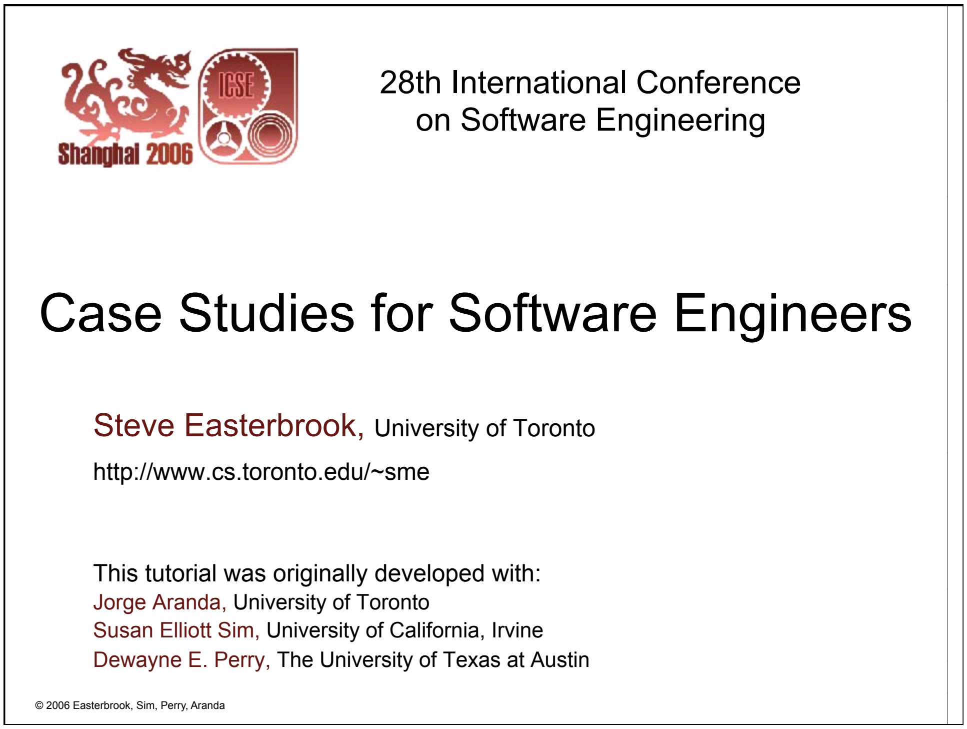

28th International Conference on Software Engineering

Case Studies for Software Engineers

Steve Easterbrook, University of Toronto

http://www.cs.toronto.edu/~sme

This tutorial was originally developed with:

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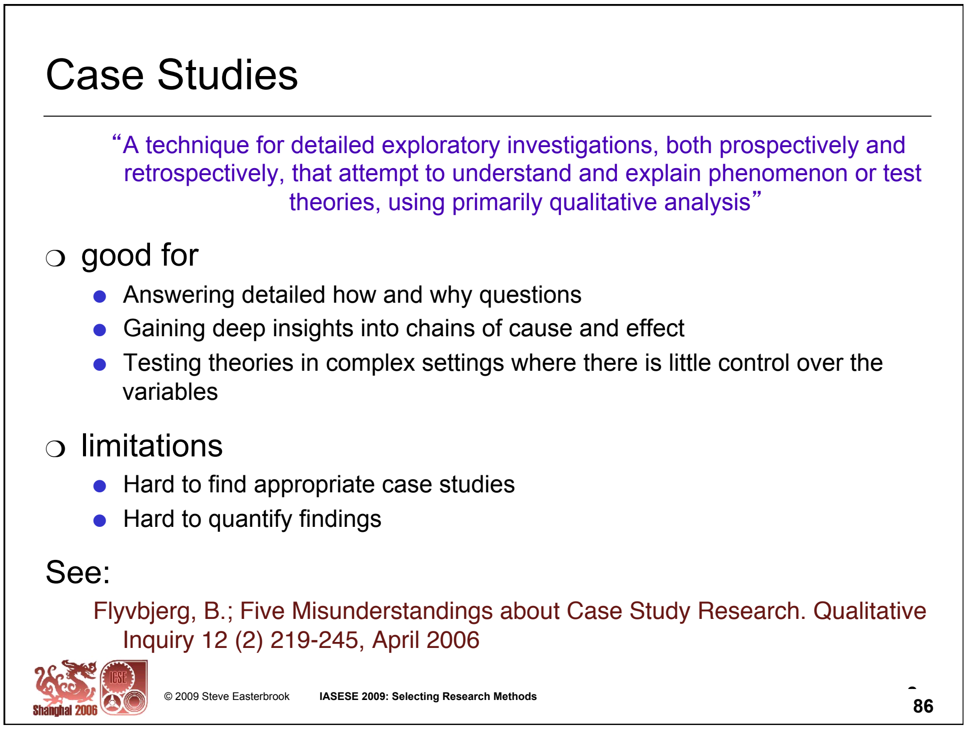


Case Studies

> "A technique for detailed exploratory investigations, both prospectively and retrospectively, that attempt to understand and explain phenomenon or test theories, using primarily qualitative analysis"

❍ good for

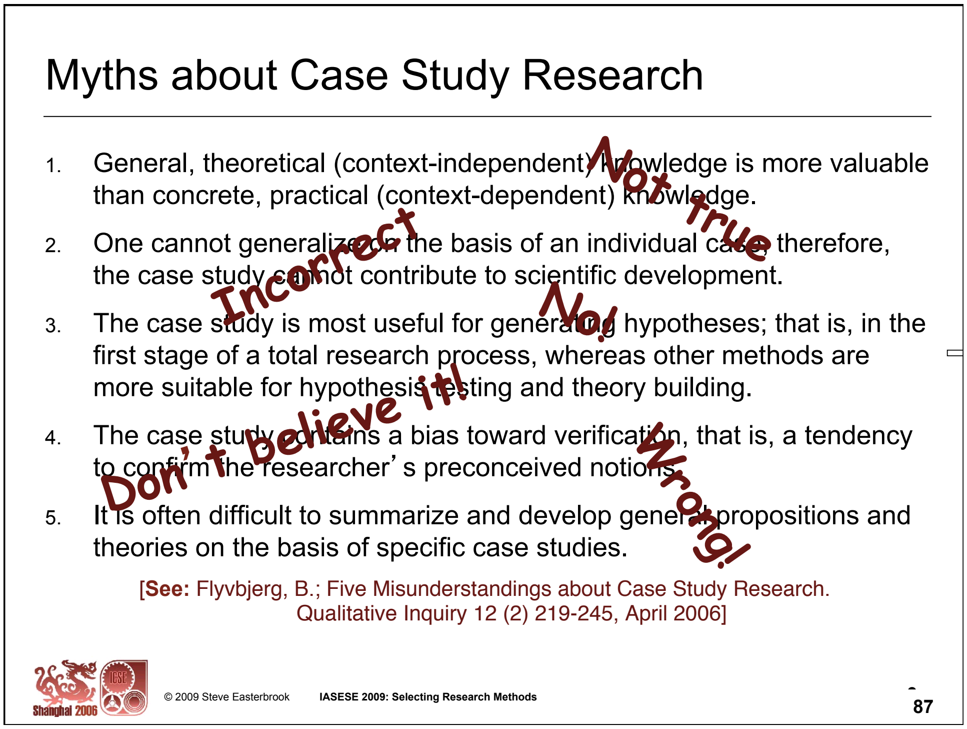
- Answering detailed how and why questions
- Gaining deep insights into chains of cause and effect
- Testing theories in complex settings where there is little control over the variables

❍ limitations

- Hard to find appropriate case studies
- Hard to quantify findings

See:

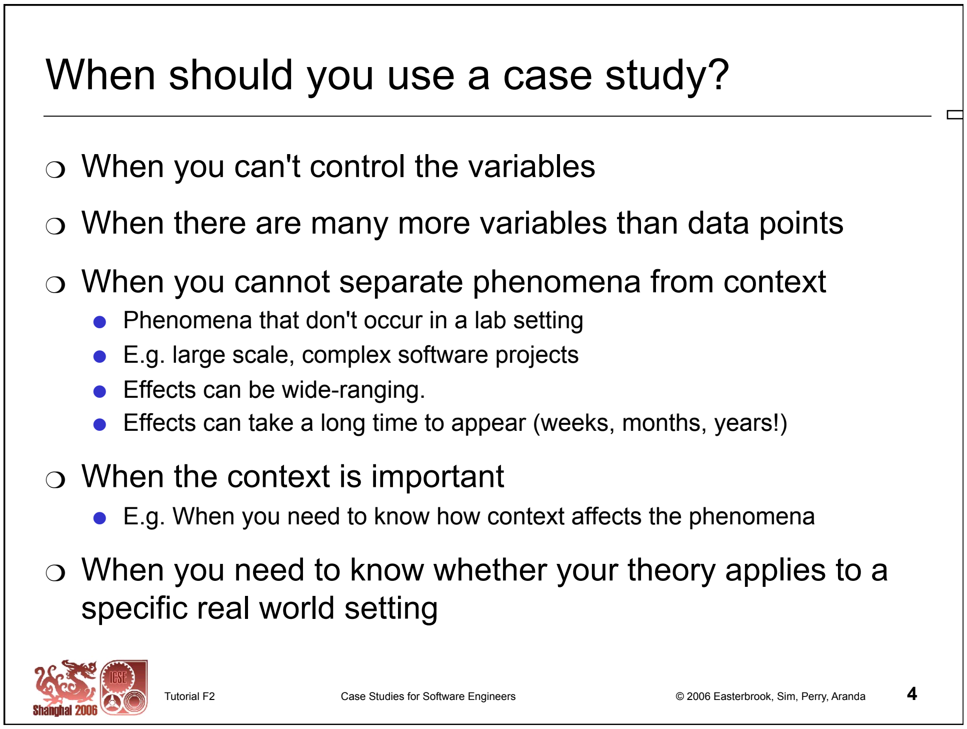
Flyvbjerg, B.; Five Misunderstandings about Case Study Research. Qualitative Inquiry 12 (2) 219-245, April 2006



Myths about Case Study Research

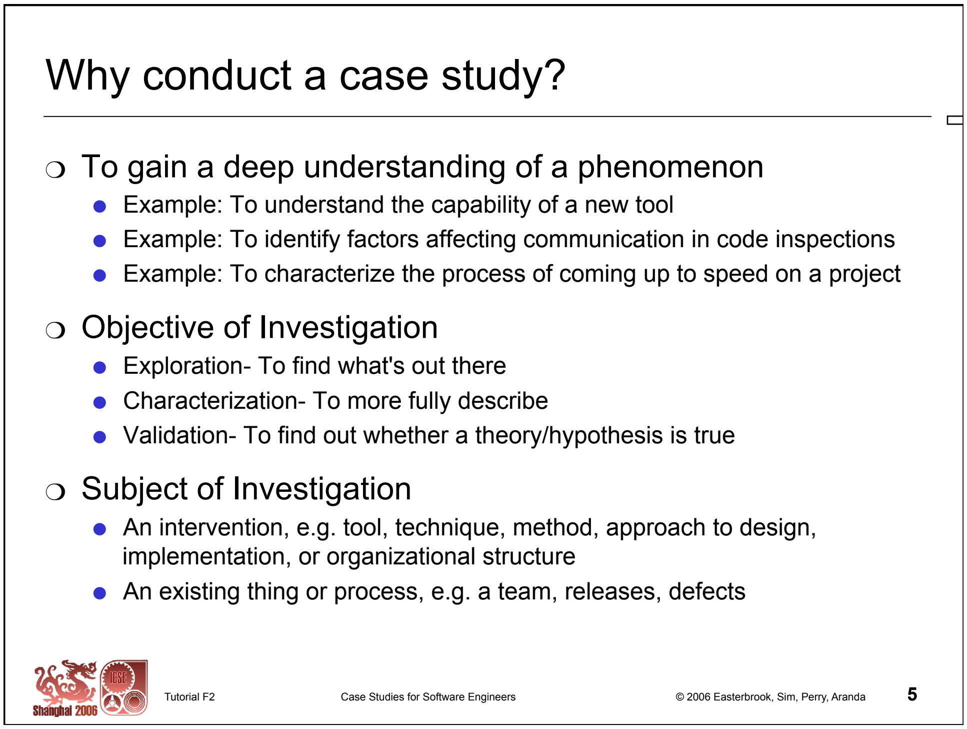
1. General, theoretical (context-independent) knowledge is more valuable than concrete, practical (context-dependent) knowledge.
2. One cannot generalize on the basis of an individual case; therefore, the case study cannot contribute to scientific development.
3. The case study is most useful for generating hypotheses; that is, in the first stage of a total research process, whereas other methods are more suitable for hypothesis testing and theory building.
4. The case study contains a bias toward verification, that is, a tendency to confirm the researcher' s preconceived notions.
5. It is often difficult to summarize and develop general propositions and theories on the basis of specific case studies.

[**See:** Flyvbjerg, B.; Five Misunderstandings about Case Study Research. Qualitative Inquiry 12 (2) 219-245, April 2006]



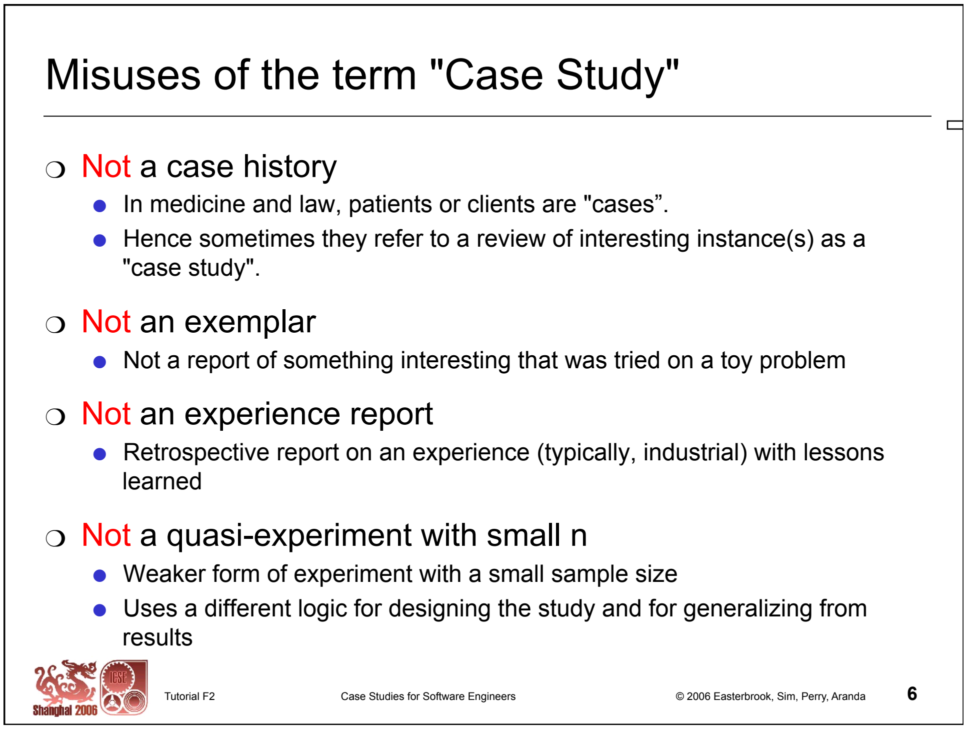
When should you use a case study?

- ❍ When you can't control the variables
- ❍ When there are many more variables than data points
- ❍ When you cannot separate phenomena from context
  - Phenomena that don't occur in a lab setting
  - E.g. large scale, complex software projects
  - Effects can be wide-ranging.
  - Effects can take a long time to appear (weeks, months, years!)
- ❍ When the context is important
  - E.g. When you need to know how context affects the phenomena
- ❍ When you need to know whether your theory applies to a specific real world setting



Why conduct a case study?

- To gain a deep understanding of a phenomenon
  - Example: To understand the capability of a new tool
  - Example: To identify factors affecting communication in code inspections
  - Example: To characterize the process of coming up to speed on a project
- Objective of Investigation
  - Exploration- To find what's out there
  - Characterization- To more fully describe
  - Validation- To find out whether a theory/hypothesis is true
- Subject of Investigation
  - An intervention, e.g. tool, technique, method, approach to design, implementation, or organizational structure
  - An existing thing or process, e.g. a team, releases, defects



Misuses of the term "Case Study"

- Not a case history
  - In medicine and law, patients or clients are "cases”.
  - Hence sometimes they refer to a review of interesting instance(s) as a "case study".
- Not an exemplar
  - Not a report of something interesting that was tried on a toy problem
- Not an experience report
  - Retrospective report on an experience (typically, industrial) with lessons learned
- Not a quasi-experiment with small n
  - Weaker form of experiment with a small sample size
  - Uses a different logic for designing the study and for generalizing from results

How can I tell it's a case study?

❍ Has research questions set out from the beginning of the study

❍ Data is collected in a planned and consistent manner

❍ Inferences are made from the data to answer the research questions

❍ Produces an explanation, description, or causal analysis of a phenomenon

- Can also be exploratory

❍ Threats to validity are addressed in a systematic way

Parts of a Case Study Research Design

❍ A research design is a "blueprint" for a study

- Deals more with the logic of the study than the logistics
- Plan for moving from questions to answers
- Ensures data is collected and analyzed to produce an answer to the initial research question
- (Analogy: research design is like a system design)

❍ Five parts of a case study research design

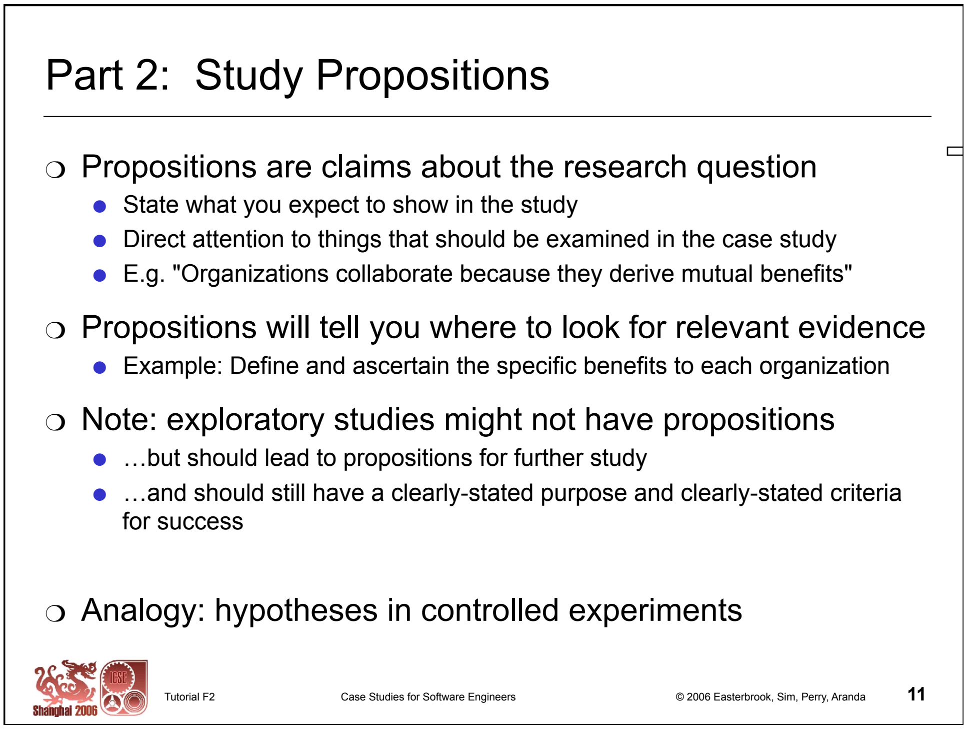
1. Research questions
2. Propositions (if any)
3. Unit(s) of analysis
4. Logic linking the data to the propositions
5. Criteria for interpreting the findings

Part 1: Study Questions

- Study design always starts with research questions
  - Clarify precisely the nature of the research question
  - Ensure the questions can be answered with a case study
  - Generally, should be "how" and "why" questions.
  - Identify and interpret the relevant theoretical constructs
- Examples:
  - "Why do two organizations have a collaborative relationship?"
  - "Why do developers prefer this tool/model/notation?"
  - "How are inspections carried out in practice?"
  - "How does agile development work in practice?"
  - "Why do programmers fail to document their code?"
  - "How does software evolve over time?"
  - "Why have formal methods not been adopted widely for safety-critical software?"
  - "How does a company identify which software projects to start?"

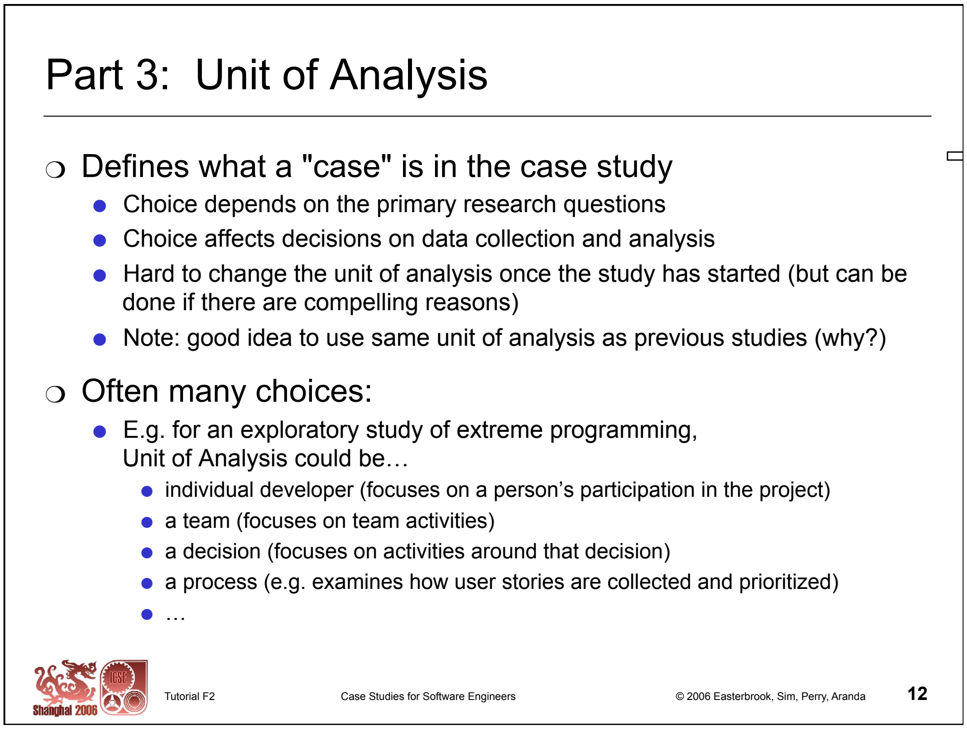
4 Types of Case Studies

- Explanatory
  - Adjudicates between competing explanations (theories)
  - E.g. How important is implementation bias in requirements engineering?
    - Rival theories: existing architectures are useful for anchoring, vs. existing architectures are over-constraining during RE
- Descriptive
  - Describes sequence of events and underlying mechanisms
  - E.g. How does pair programming actually work?
  - E.g. How do software immigrants naturalize?
- Causal
  - Looks for causal relationship between concepts
  - E.g. How do requirements errors and programming errors affect safety in real time control systems?
    - See study by Robyn Lutz on the Voyager and Galileo spacecraft
- Exploratory
  - Used to build new theories where we don't have any yet
  - Choose cases that meet particular criteria or parameters
  - E.g. Christopher Columbus' voyage to the new world
  - E.g. What do CMM level 3 organizations have in common?



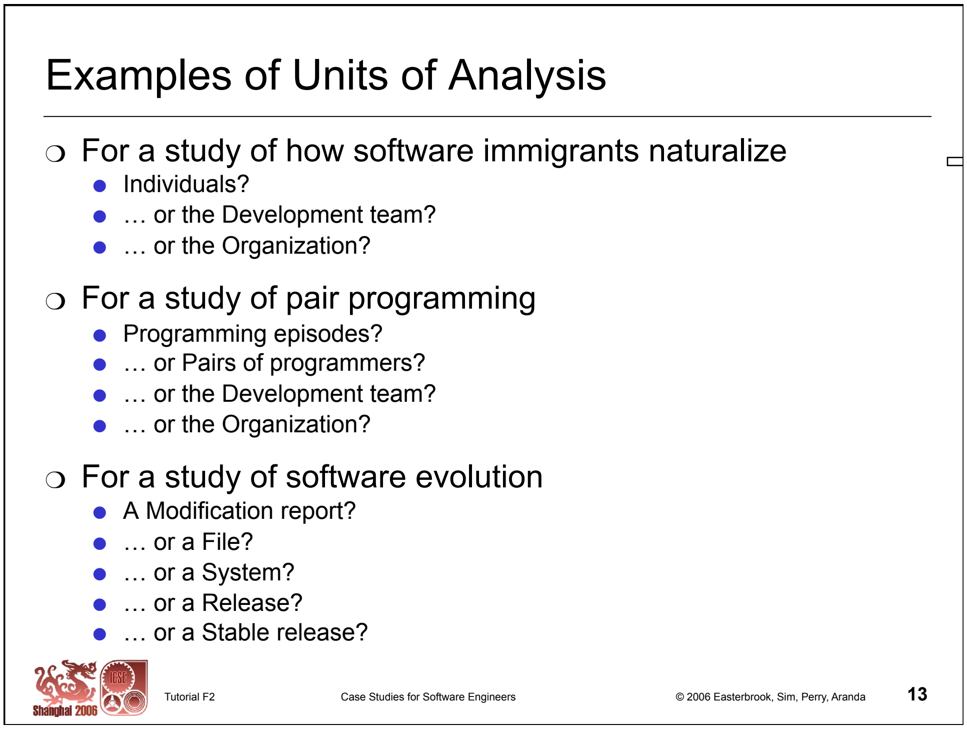
Part 2: Study Propositions

- Propositions are claims about the research question
  - State what you expect to show in the study
  - Direct attention to things that should be examined in the case study
  - E.g. "Organizations collaborate because they derive mutual benefits"
- Propositions will tell you where to look for relevant evidence
  - Example: Define and ascertain the specific benefits to each organization
- Note: exploratory studies might not have propositions
  - …but should lead to propositions for further study
  - …and should still have a clearly-stated purpose and clearly-stated criteria for success
- Analogy: hypotheses in controlled experiments



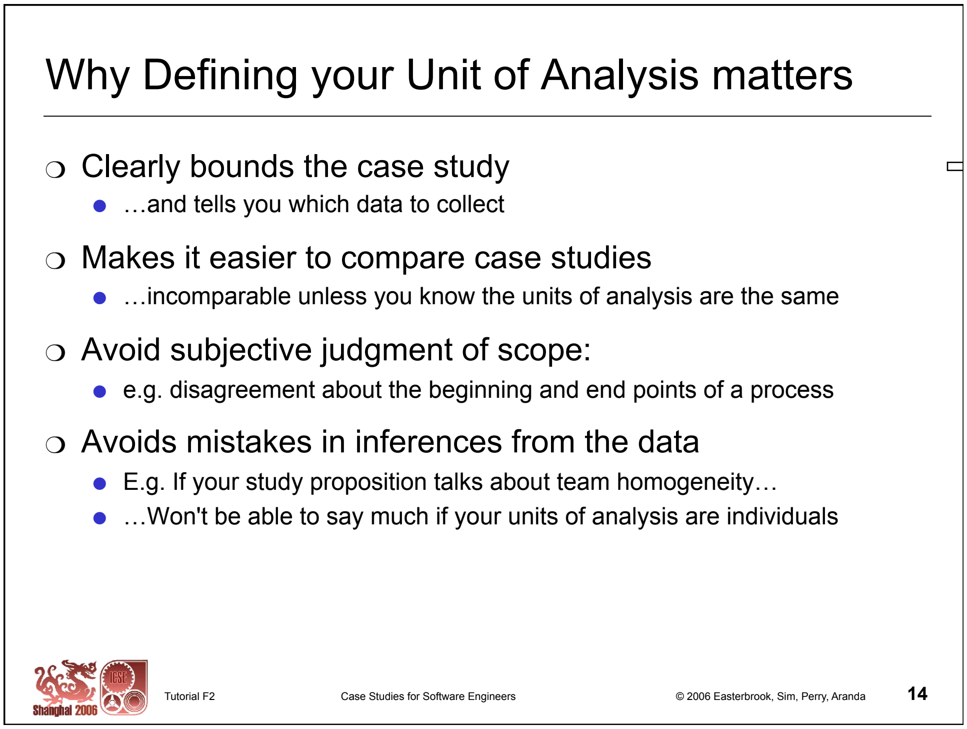
Part 3: Unit of Analysis

- Defines what a "case" is in the case study
  - Choice depends on the primary research questions
  - Choice affects decisions on data collection and analysis
  - Hard to change the unit of analysis once the study has started (but can be done if there are compelling reasons)
  - Note: good idea to use same unit of analysis as previous studies (why?)
- Often many choices:
  - E.g. for an exploratory study of extreme programming, Unit of Analysis could be…
    - individual developer (focuses on a person’s participation in the project)
    - a team (focuses on team activities)
    - a decision (focuses on activities around that decision)
    - a process (e.g. examines how user stories are collected and prioritized)
    - …



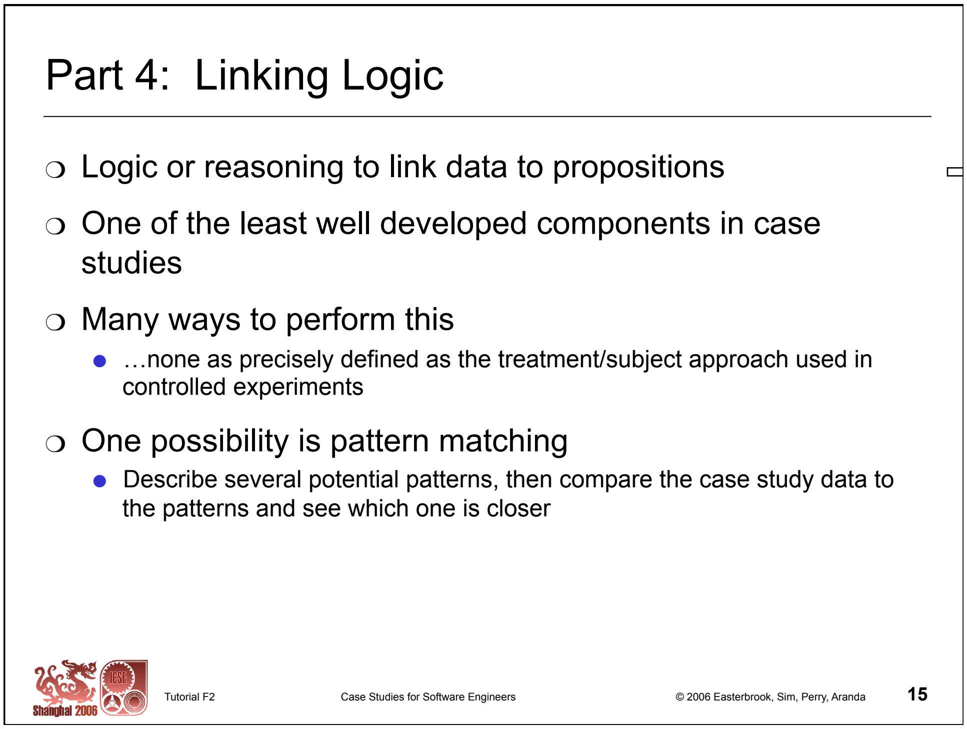
Examples of Units of Analysis

- For a study of how software immigrants naturalize
  - Individuals?
  - … or the Development team?
  - … or the Organization?
- For a study of pair programming
  - Programming episodes?
  - … or Pairs of programmers?
  - … or the Development team?
  - … or the Organization?
- For a study of software evolution
  - A Modification report?
  - … or a File?
  - … or a System?
  - … or a Release?
  - … or a Stable release?



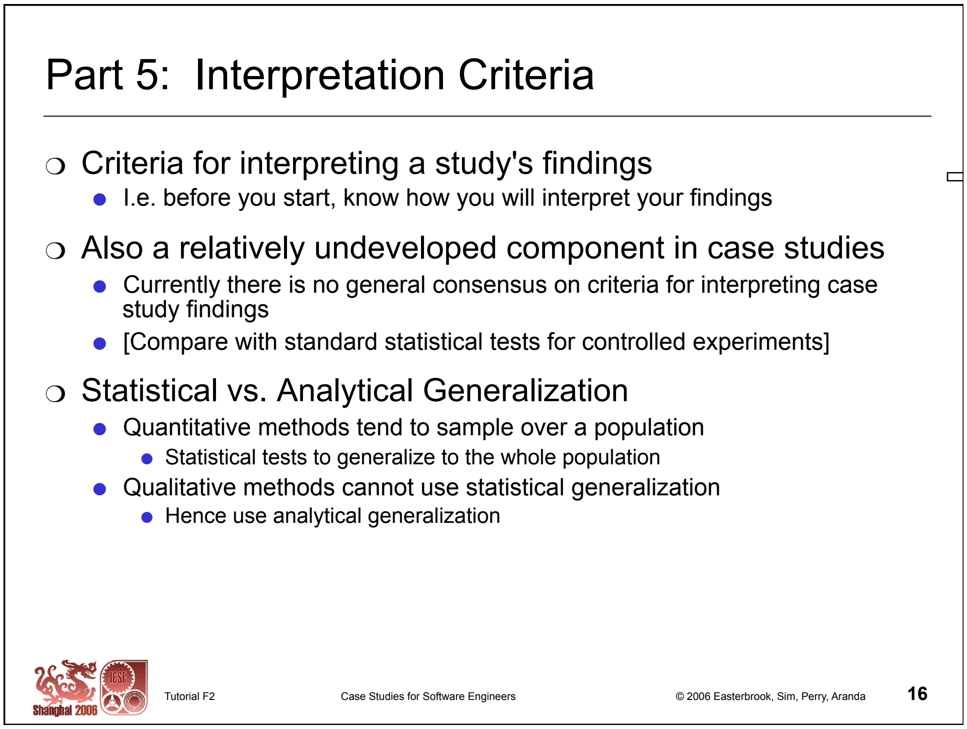
Why Defining your Unit of Analysis matters

- Clearly bounds the case study
  - …and tells you which data to collect
- Makes it easier to compare case studies
  - …incomparable unless you know the units of analysis are the same
- Avoid subjective judgment of scope:
  - e.g. disagreement about the beginning and end points of a process
- Avoids mistakes in inferences from the data
  - E.g. If your study proposition talks about team homogeneity…
  - …Won't be able to say much if your units of analysis are individuals



Part 4: Linking Logic

- Logic or reasoning to link data to propositions
- One of the least well developed components in case studies
- Many ways to perform this
  - …none as precisely defined as the treatment/subject approach used in controlled experiments
- One possibility is pattern matching
  - Describe several potential patterns, then compare the case study data to the patterns and see which one is closer



Part 5: Interpretation Criteria

- Criteria for interpreting a study's findings
  - I.e. before you start, know how you will interpret your findings
- Also a relatively undeveloped component in case studies
  - Currently there is no general consensus on criteria for interpreting case study findings
  - [Compare with standard statistical tests for controlled experiments]
- Statistical vs. Analytical Generalization
  - Quantitative methods tend to sample over a population
    - Statistical tests to generalize to the whole population
  - Qualitative methods cannot use statistical generalization
    - Hence use analytical generalization

Generalization

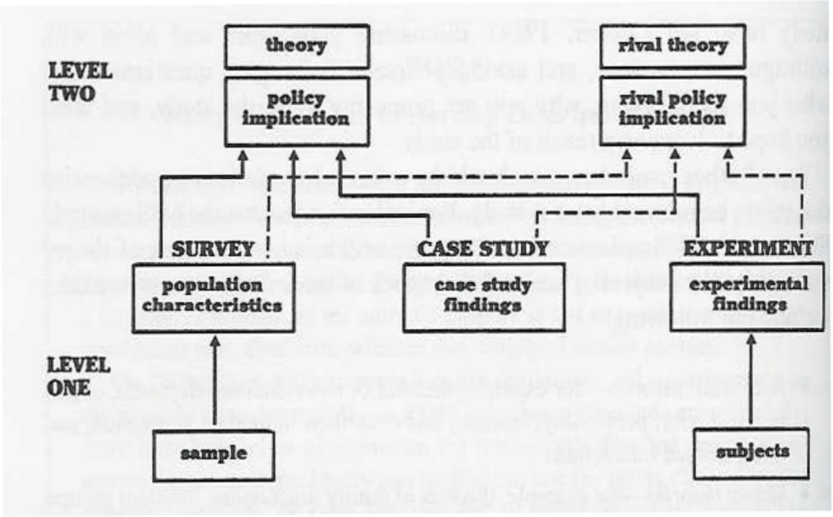
Statistical Generalization

- First level generalization:
  - From sample to population
- Well understood and widely used in empirical studies
- Can only be used for quantifiable variables
- Based on random sampling:
  - Standard statistical tests tell you if results on a sample apply to the whole population
- Not useful for case studies
  - No random sampling
  - Rarely enough data points

Analytical Generalization

- Second level generalization:
  - From findings to theory
- Compares qualitative findings with the theory:
  - Does the data support or refute the theory?
  - Or: do they support this theory better than rival theories?
- Supports empirical induction:
  - Evidence builds if subsequent case studies also support the theory (& fail to support rival theories)
- More powerful than statistical techniques
  - Doesn't rely on correlations
  - Examines underlying mechanisms

Analytical and Statistical Generalization



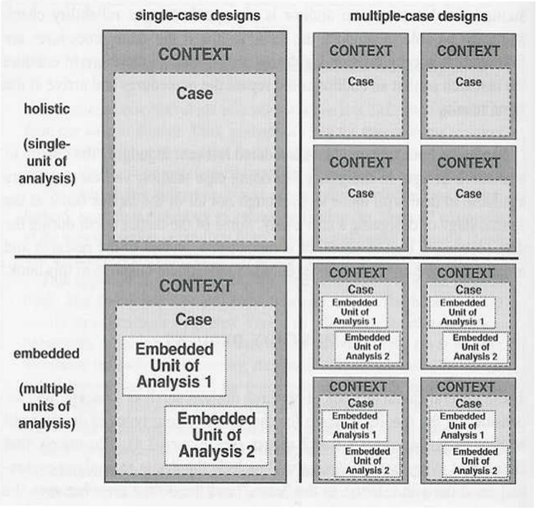
How can I evaluate a case study?

Same criteria as for other empirical research:

- Construct Validity
  - Concepts being studied are operationalized and measured correctly
- Internal Validity
  - Establish a causal relationship and distinguish spurious relationships
- External Validity
  - Establish the domain to which a study's findings can be generalized
- Empirical Reliability
  - Demonstrate that the study can be repeated with the same results

Case Study Designs

- 4 types of designs (based on a 2x2 matrix)
  - Single-case vs. Multiple-case design
  - Holistic vs. Embedded design

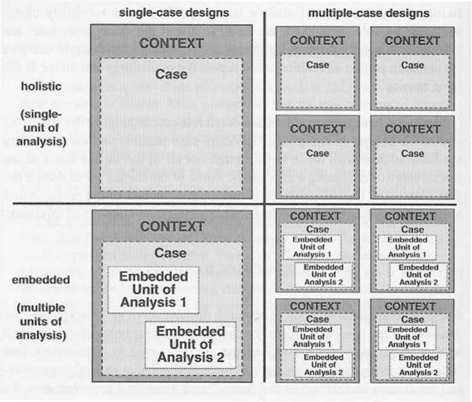

single-case designs
multiple-case designs
holistic
(single-unit of analysis)
embedded
(multiple units of analysis)
CONTEXT
Case
Embedded Unit of Analysis 1
Embedded Unit of Analysis 2

Basic Types of Designs for Case Studies (Yin, page 40)

Holistic vs. Embedded Case Studies

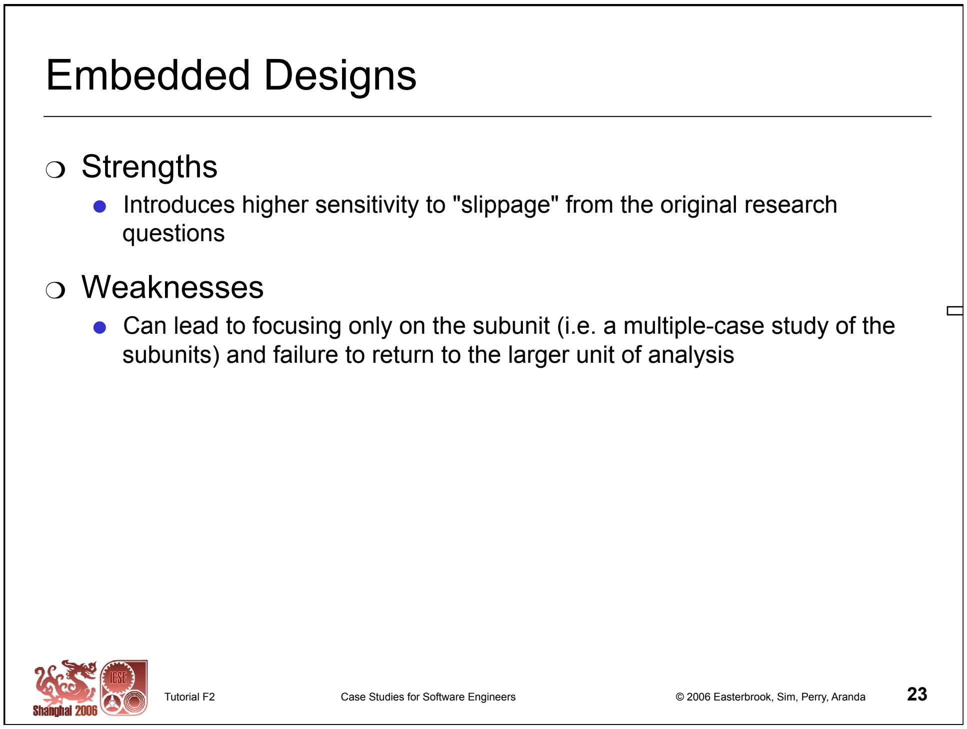
- *Holistic* case study: Examines only the global nature of one unit of analysis (not any subunits)
  - E.g: a case study about an organization

- *Embedded* case study: Involves more than one unit of analysis by paying attention to subunit(s) within the case
  - E.g: a case study about a single organization may have conclusions about the people (subunits) within the organization


single-case designs
multiple-case designs
holistic
(single-unit of analysis)
embedded
(multiple units of analysis)
CONTEXT
Case
Embedded Unit of Analysis 1
Embedded Unit of Analysis 2

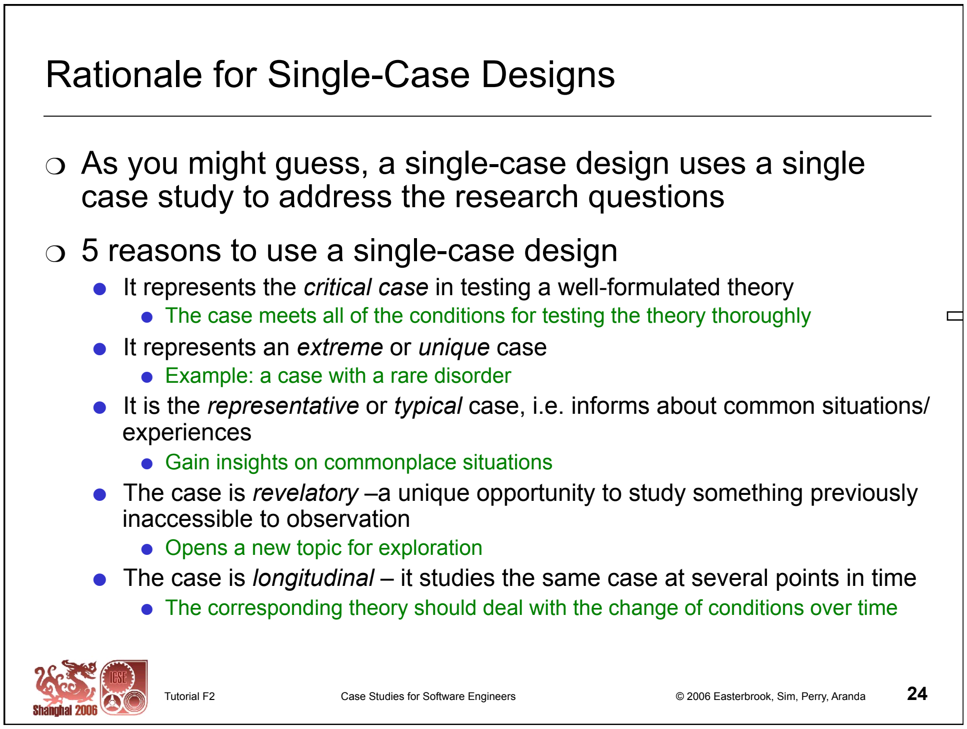
Holistic Designs

- Strengths
  - Convenient when no logical subunits can be defined
  - Good when the relevant theory underlying the case study is holistic in nature
- Weaknesses
  - Can lead to abstract studies with no clear measures or data
  - Harder to detect when the case study is shifting focus away from initial research questions



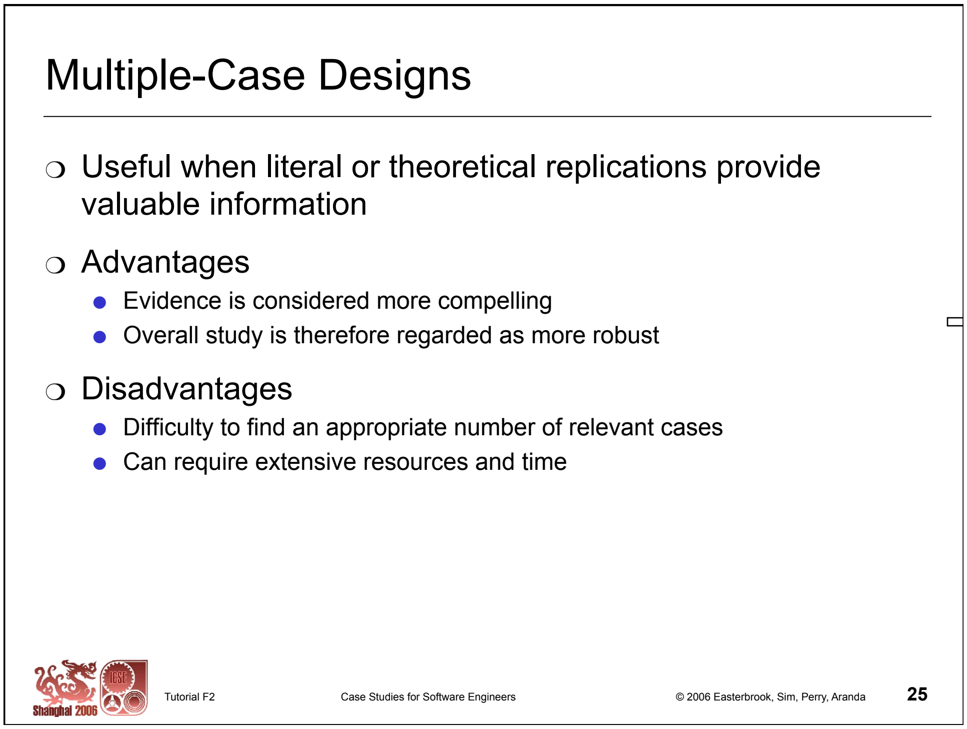
Embedded Designs

- Strengths
  - Introduces higher sensitivity to "slippage" from the original research questions
- Weaknesses
  - Can lead to focusing only on the subunit (i.e. a multiple-case study of the subunits) and failure to return to the larger unit of analysis



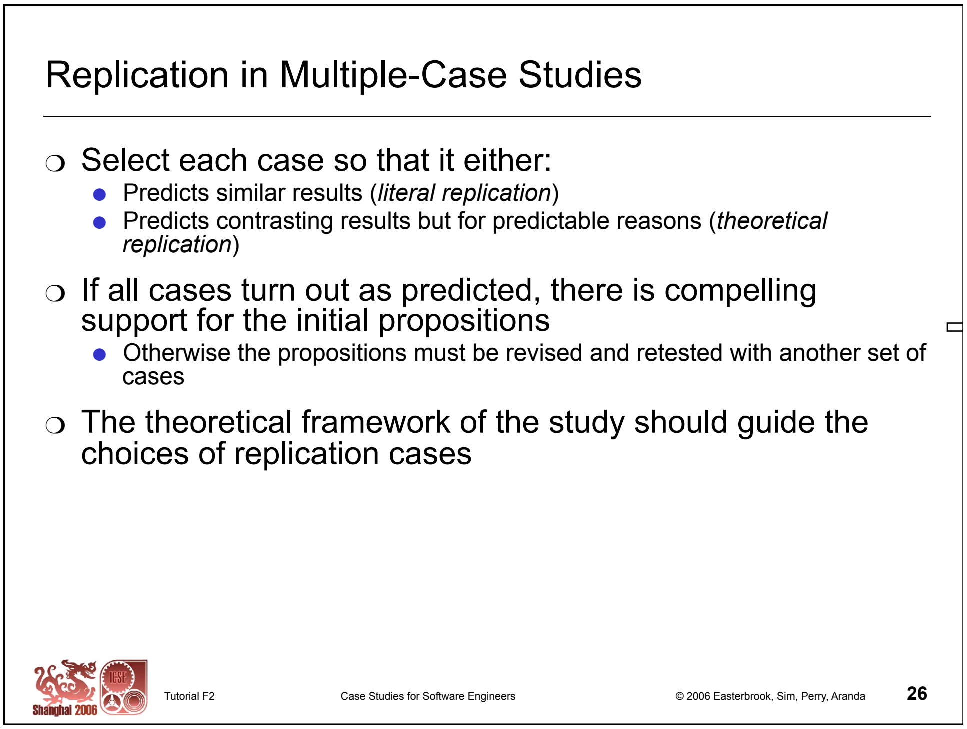
Rationale for Single-Case Designs

- As you might guess, a single-case design uses a single case study to address the research questions
- 5 reasons to use a single-case design
  - It represents the *critical case* in testing a well-formulated theory
    - The case meets all of the conditions for testing the theory thoroughly
  - It represents an *extreme* or *unique* case
    - Example: a case with a rare disorder
  - It is the *representative* or *typical* case, i.e. informs about common situations/ experiences
    - Gain insights on commonplace situations
  - The case is *revelatory* –a unique opportunity to study something previously inaccessible to observation
    - Opens a new topic for exploration
  - The case is *longitudinal* – it studies the same case at several points in time
    - The corresponding theory should deal with the change of conditions over time



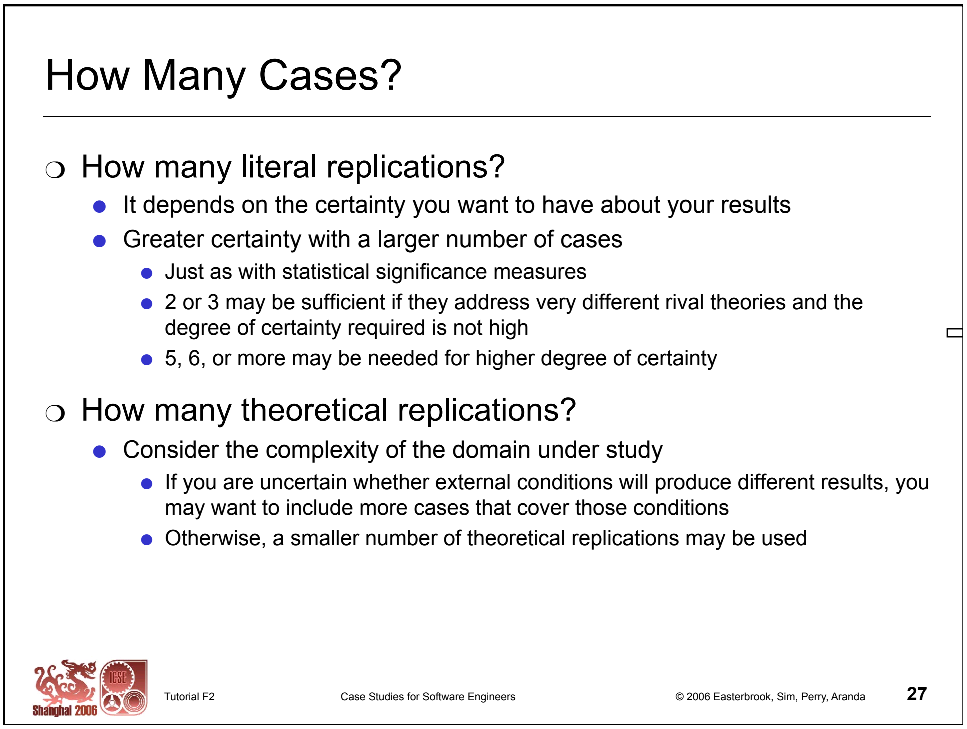
Multiple-Case Designs

- Useful when literal or theoretical replications provide valuable information
- Advantages
  - Evidence is considered more compelling
  - Overall study is therefore regarded as more robust
- Disadvantages
  - Difficulty to find an appropriate number of relevant cases
  - Can require extensive resources and time



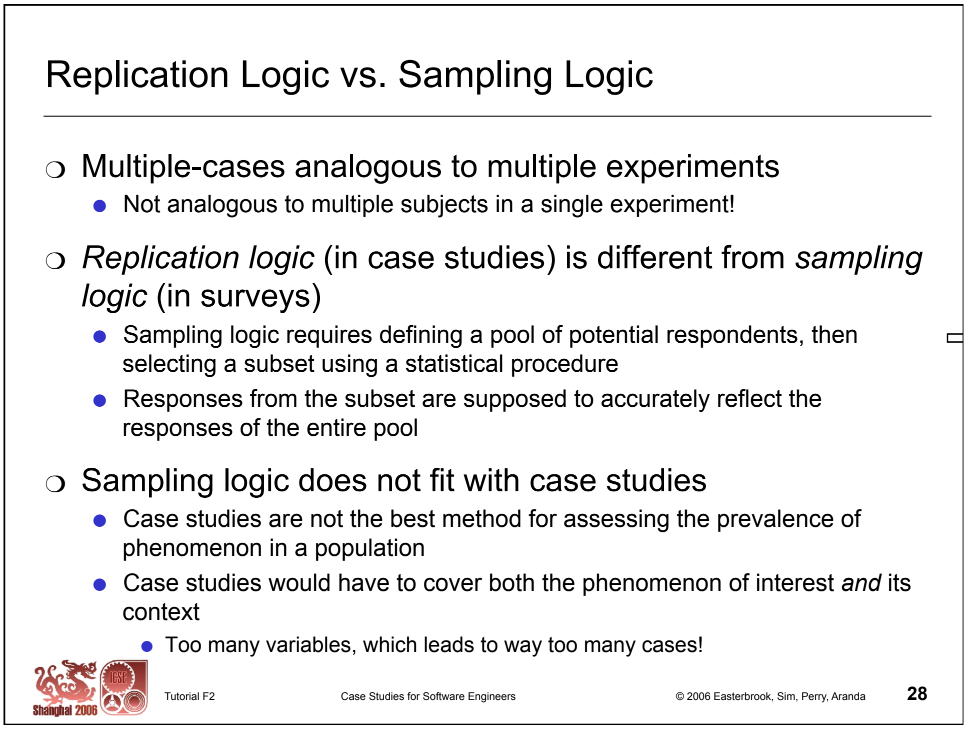
Replication in Multiple-Case Studies

- Select each case so that it either:
  - Predicts similar results (*literal replication*)
  - Predicts contrasting results but for predictable reasons (*theoretical replication*)
- If all cases turn out as predicted, there is compelling support for the initial propositions
  - Otherwise the propositions must be revised and retested with another set of cases
- The theoretical framework of the study should guide the choices of replication cases



How Many Cases?

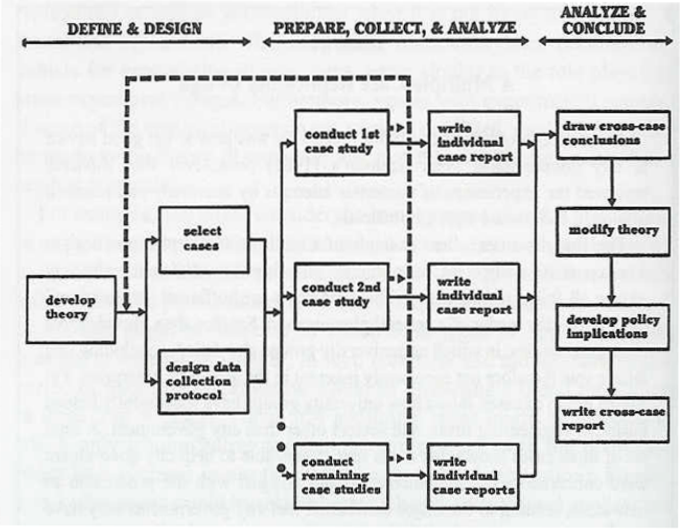
- ❍ How many literal replications?
  - It depends on the certainty you want to have about your results
  - Greater certainty with a larger number of cases
    - Just as with statistical significance measures
    - 2 or 3 may be sufficient if they address very different rival theories and the degree of certainty required is not high
    - 5, 6, or more may be needed for higher degree of certainty
- ❍ How many theoretical replications?
  - Consider the complexity of the domain under study
    - If you are uncertain whether external conditions will produce different results, you may want to include more cases that cover those conditions
    - Otherwise, a smaller number of theoretical replications may be used



Replication Logic vs. Sampling Logic

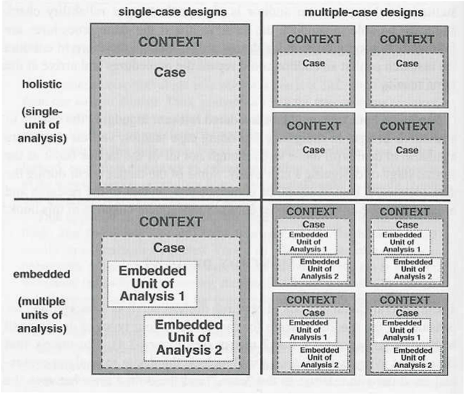
- ❍ Multiple-cases analogous to multiple experiments
  - Not analogous to multiple subjects in a single experiment!
- ❍ *Replication logic* (in case studies) is different from *sampling logic* (in surveys)
  - Sampling logic requires defining a pool of potential respondents, then selecting a subset using a statistical procedure
  - Responses from the subset are supposed to accurately reflect the responses of the entire pool
- ❍ Sampling logic does not fit with case studies
  - Case studies are not the best method for assessing the prevalence of phenomenon in a population
  - Case studies would have to cover both the phenomenon of interest *and* its context
    - Too many variables, which leads to way too many cases!

Replication Approach for Multiple-Case Studies


DEFINE & DESIGN
PREPARE, COLLECT, & ANALYZE
ANALYZE & CONCLUDE
develop theory
select cases
design data collection protocol
conduct 1st case study
conduct 2nd case study
conduct remaining case studies
write individual case report
write individual case report
write individual case reports
draw cross-case conclusions
modify theory
develop policy implications
write cross-case report

Case Study Method (Yin page 50)

Multiple-Case Designs: Holistic or Embedded


single-case designs
multiple-case designs
holistic
(single-unit of analysis)
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(multiple units of analysis)
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Case
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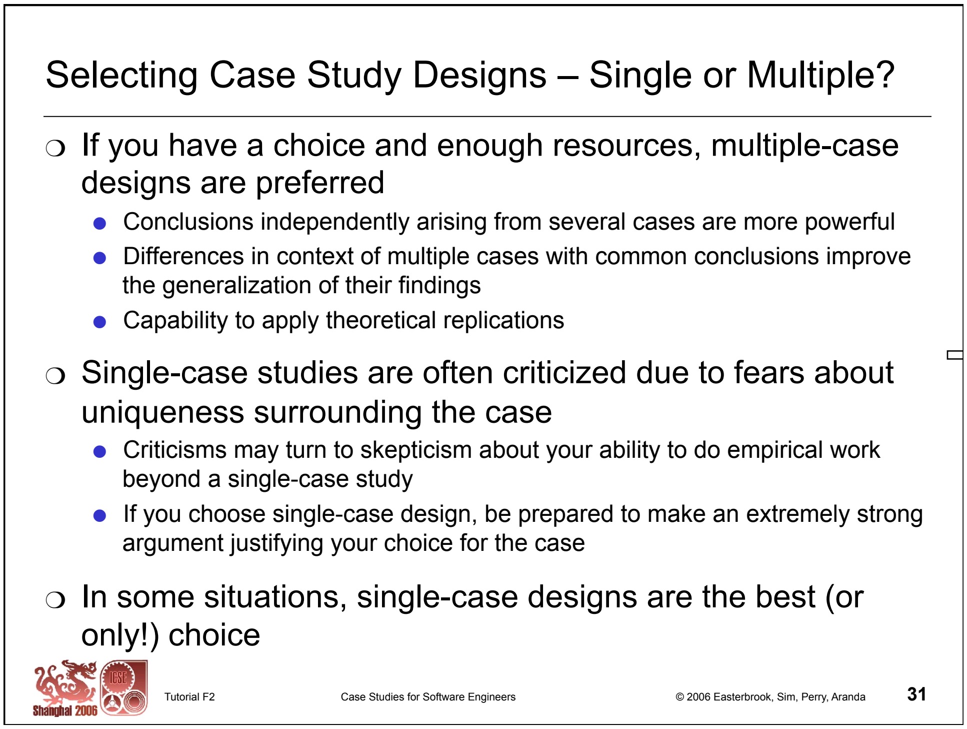
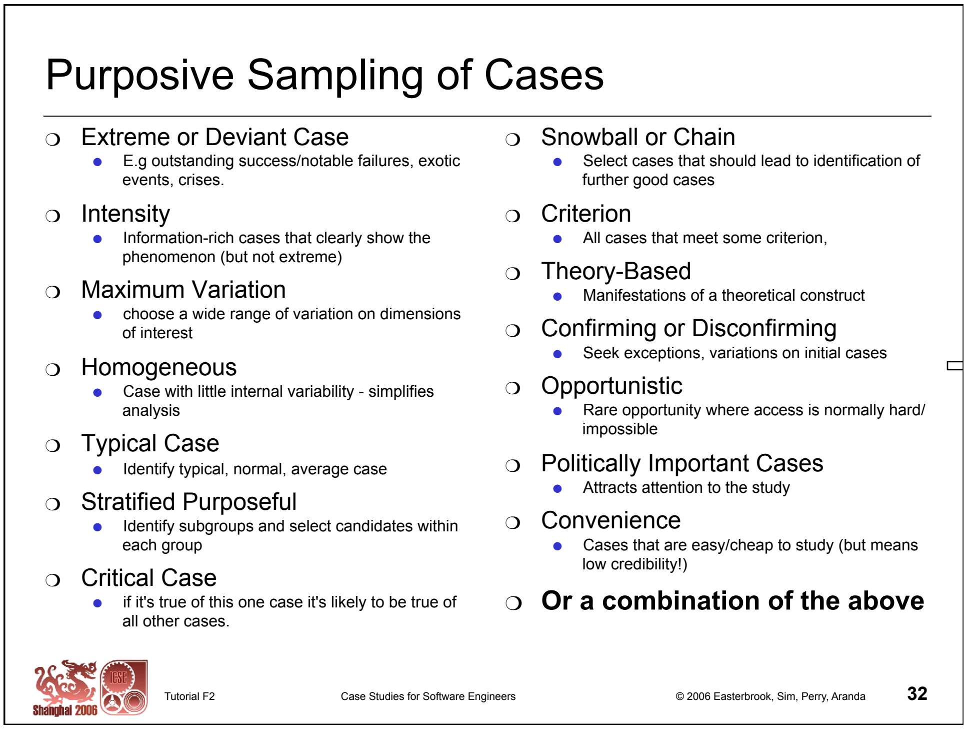
Embedded Unit of Analysis 2

- A multiple-case study can consist of multiple holistic or multiple embedded cases
  - But there is no mixing of embedded and holistic cases in the same study
- Note that for embedded studies, subunit data are *not* pooled across subunits
  - Used to draw conclusions only for the subunit's case



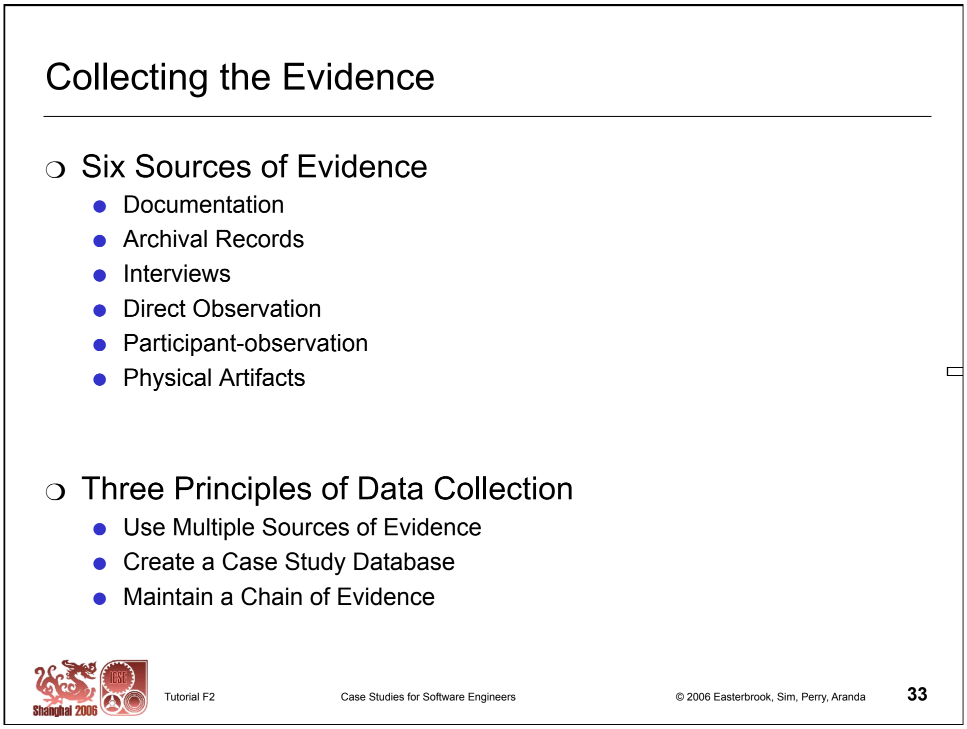
Selecting Case Study Designs – Single or Multiple?

- ❍ If you have a choice and enough resources, multiple-case designs are preferred
  - Conclusions independently arising from several cases are more powerful
  - Differences in context of multiple cases with common conclusions improve the generalization of their findings
  - Capability to apply theoretical replications
- ❍ Single-case studies are often criticized due to fears about uniqueness surrounding the case
  - Criticisms may turn to skepticism about your ability to do empirical work beyond a single-case study
  - If you choose single-case design, be prepared to make an extremely strong argument justifying your choice for the case
- ❍ In some situations, single-case designs are the best (or only!) choice



Purposive Sampling of Cases

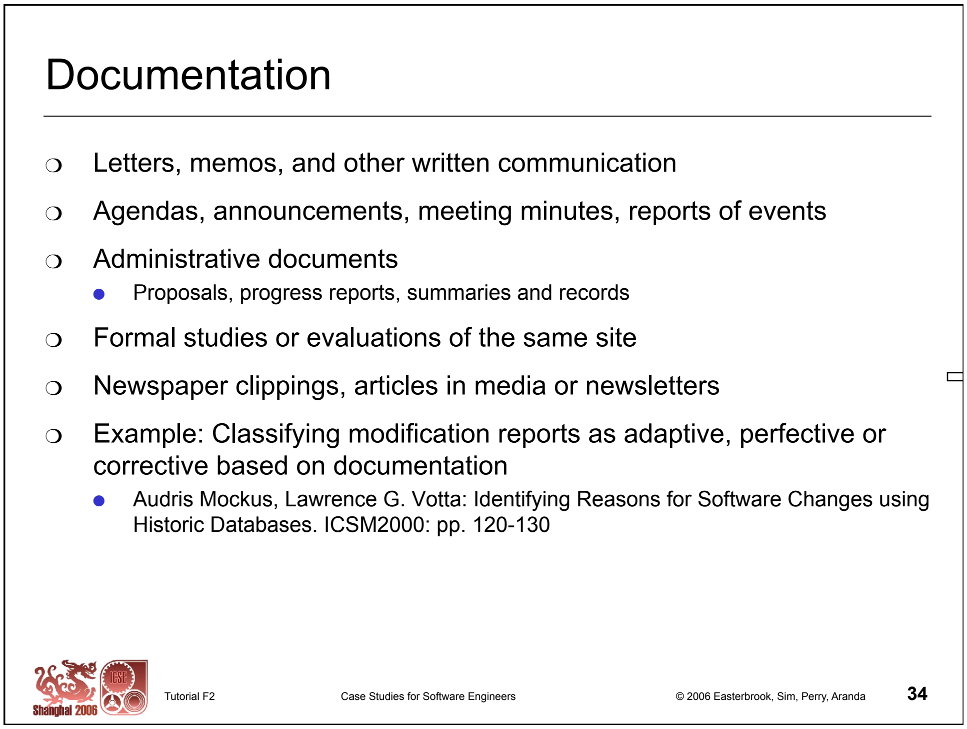
- ❍ Extreme or Deviant Case
  - E.g outstanding success/notable failures, exotic events, crises.
- ❍ Intensity
  - Information-rich cases that clearly show the phenomenon (but not extreme)
- ❍ Maximum Variation
  - choose a wide range of variation on dimensions of interest
- ❍ Homogeneous
  - Case with little internal variability - simplifies analysis
- ❍ Typical Case
  - Identify typical, normal, average case
- ❍ Stratified Purposeful
  - Identify subgroups and select candidates within each group
- ❍ Critical Case
  - if it's true of this one case it's likely to be true of all other cases.
- ❍ Snowball or Chain
  - Select cases that should lead to identification of further good cases
- ❍ Criterion
  - All cases that meet some criterion,
- ❍ Theory-Based
  - Manifestations of a theoretical construct
- ❍ Confirming or Disconfirming
  - Seek exceptions, variations on initial cases
- ❍ Opportunistic
  - Rare opportunity where access is normally hard/ impossible
- ❍ Politically Important Cases
  - Attracts attention to the study
- ❍ Convenience
  - Cases that are easy/cheap to study (but means low credibility!)
- ❍ **Or a combination of the above**



Collecting the Evidence

❍ Six Sources of Evidence
- Documentation
- Archival Records
- Interviews
- Direct Observation
- Participant-observation
- Physical Artifacts

❍ Three Principles of Data Collection
- Use Multiple Sources of Evidence
- Create a Case Study Database
- Maintain a Chain of Evidence



Documentation

❍ Letters, memos, and other written communication

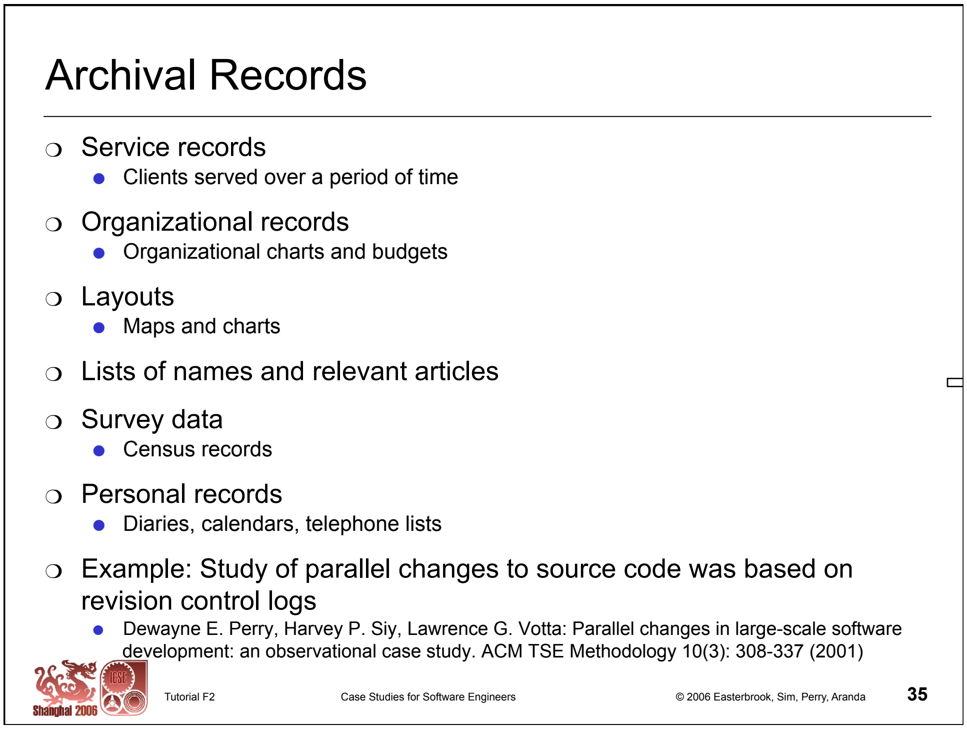
❍ Agendas, announcements, meeting minutes, reports of events

❍ Administrative documents
- Proposals, progress reports, summaries and records

❍ Formal studies or evaluations of the same site

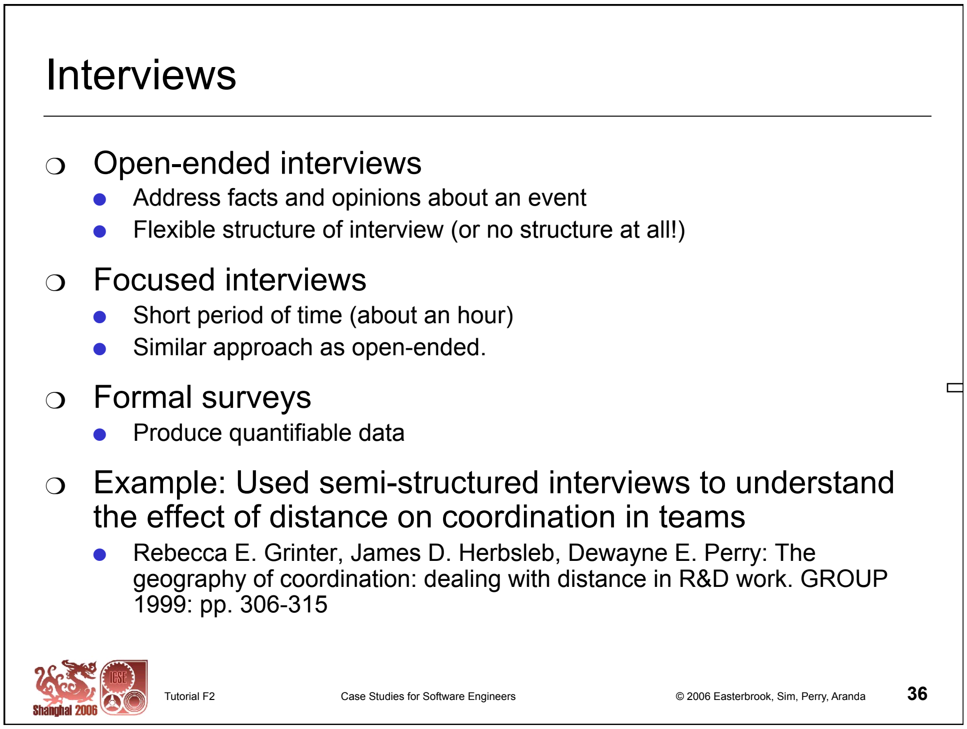
❍ Newspaper clippings, articles in media or newsletters

❍ Example: Classifying modification reports as adaptive, perfective or corrective based on documentation
- Audris Mockus, Lawrence G. Votta: Identifying Reasons for Software Changes using Historic Databases. ICSM2000: pp. 120-130



Archival Records

- Service records
  - Clients served over a period of time
- Organizational records
  - Organizational charts and budgets
- Layouts
  - Maps and charts
- Lists of names and relevant articles
- Survey data
  - Census records
- Personal records
  - Diaries, calendars, telephone lists
- Example: Study of parallel changes to source code was based on revision control logs
  - Dewayne E. Perry, Harvey P. Siy, Lawrence G. Votta: Parallel changes in large-scale software development: an observational case study. ACM TSE Methodology 10(3): 308-337 (2001)



Interviews

- Open-ended interviews
  - Address facts and opinions about an event
  - Flexible structure of interview (or no structure at all!)
- Focused interviews
  - Short period of time (about an hour)
  - Similar approach as open-ended.
- Formal surveys
  - Produce quantifiable data
- Example: Used semi-structured interviews to understand the effect of distance on coordination in teams
  - Rebecca E. Grinter, James D. Herbsleb, Dewayne E. Perry: The geography of coordination: dealing with distance in R&D work. GROUP 1999: pp. 306-315

Direct Observation

- Field visits- creates opportunity for direct observation
- Photographs of site
  - Need permission in order to proceed!
- Can be used to calibrate self-reports
  - Example: Informal, impromptu interactions
- Example: Followed software developers around to characterize how they spend their time
  - Dewayne E. Perry, Nancy A. Staudenmayer, Lawrence G. Votta: People, Organizations, and Process Improvement. IEEE Software 11(4): 36-45 (1994)

Participant-observation

- Not a passive observer, but actually participate in setting
  - Employee of the company under study
- Provides an opportunity to understand the rationale and behavior of people and organization being studied
- Example: Seaman participated in 23 code inspections over period of five months at NASA/Goddard Space Flight Center's Flight Dynamics Division
  - Carolyn B. Seaman, Victor R. Basili: Communication and Organization: An Empirical Study of Discussion in Inspection Meetings. IEEE Trans. Software Eng. 24(7): 559-572 (1998)

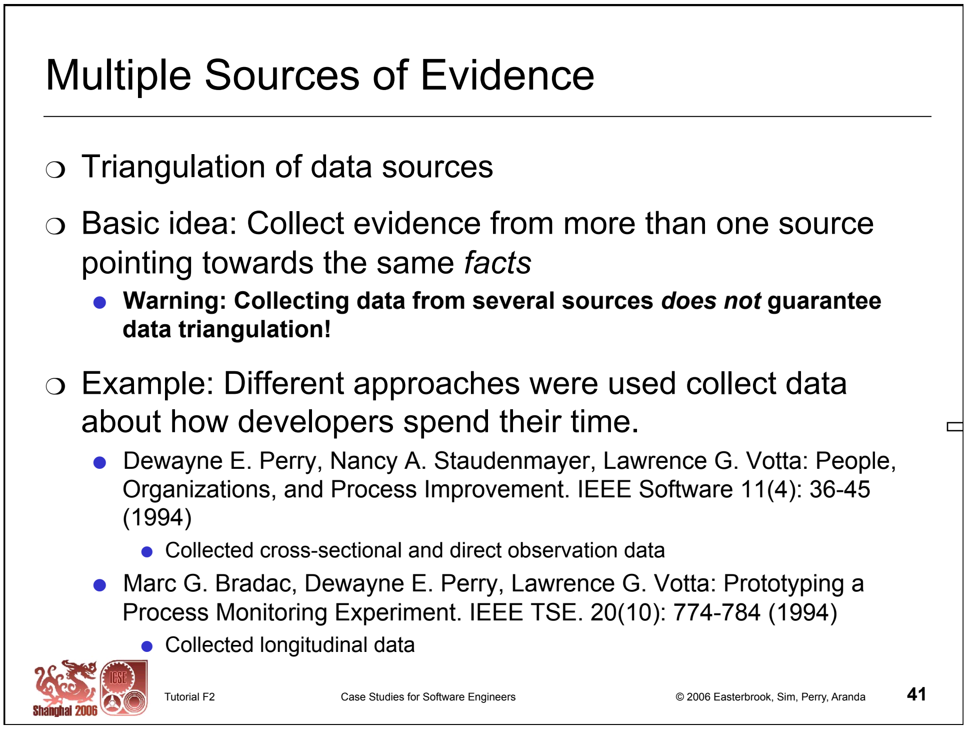
Physical Artifacts

- Technological tool, instrument, or device
- Artifacts can be collected or observed as part a field visit
- Works of art or types of physical evidence
- Example: Diachronic study of art records to determine whether right-handedness was a recent or old trait
  - Two rival hypotheses: Physiological predisposition vs Social/ environmental pressure
  - Tested by counting unimanual tool usage in art representations
  - 1200 examples from 1500 BC to 1950, world sources
  - 92.6% used right hand
  - Geo/historical distribution uniformly high
  - Seems to support physiological interpretation that right-handedness is an age-old trait

Principles of Data Collection

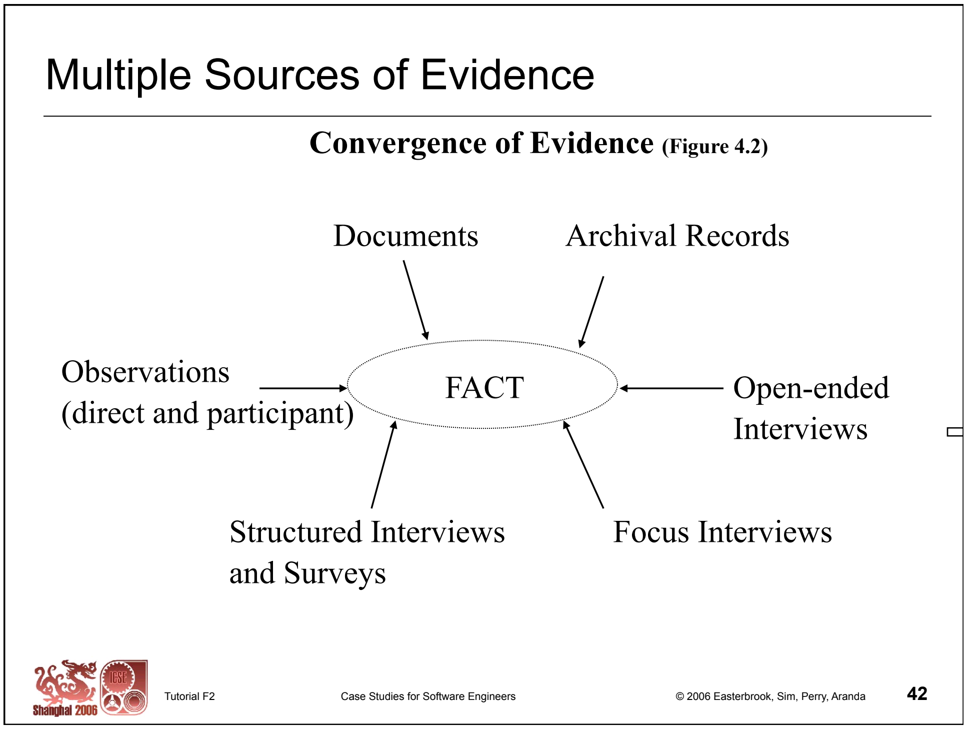
- Use Multiple Sources of Evidence
- Create a Case Study Database
- Maintain a Chain of Evidence

These principles can be applied to all six data collection methods



Multiple Sources of Evidence

- ❍ Triangulation of data sources
- ❍ Basic idea: Collect evidence from more than one source pointing towards the same *facts*
  - ● **Warning: Collecting data from several sources *does not* guarantee data triangulation!**
- ❍ Example: Different approaches were used collect data about how developers spend their time.
  - ● Dewayne E. Perry, Nancy A. Staudenmayer, Lawrence G. Votta: People, Organizations, and Process Improvement. IEEE Software 11(4): 36-45 (1994)
    - ● Collected cross-sectional and direct observation data
  - ● Marc G. Bradac, Dewayne E. Perry, Lawrence G. Votta: Prototyping a Process Monitoring Experiment. IEEE TSE. 20(10): 774-784 (1994)
    - ● Collected longitudinal data



Multiple Sources of Evidence

Convergence of Evidence (Figure 4.2)

Documents

Archival Records

Observations (direct and participant)

FACT

Open-ended Interviews

Structured Interviews and Surveys

Focus Interviews