Reuse and Quality Enhancement via Computation and Distribution of Component Derivative Rewards

Juan-Antonio Carballo, Wendy Belluomini, Robert Montoye, and David Cohn

IBM Austin Research Laboratory, Austin, TX 78758, U.S.A.

Abstract

Given today's stringent cost, time-to-market, and quality constraints, it is imperative that design teams evaluate the potential for system components to be implemented with previously designed components. A methodology and system for encouraging reuse as a design principle and rewarding both the design of reusable components and the subsequent reuse of such components is presented. If a decision is made to forego previously designed components, the design team is encouraged to incorporate reusability principles into the component design by a reward or compensation structure that rewards both the individual members of a team as well as the corporate entity to which the design team is assigned. The reward structure also encourages teams to use existing designs wherever possible by rewarding a team that reuses an existing component. An administrator may adjust the relative rewards for incorporating reusability into a design vs. reusing a design to modulate a preference for innovation in selected areas.

1 Introduction

The designers and manufacturers of complex electronic systems are frequently large corporations that are fragmented into smaller entities such as divisions or product groups and still further fragmented into design teams that work on specific design blocks. A design team is assigned the task of completing a design according to some specification, market demand, customer requirement, or some combination thereof. A paramount determinant of the design team's success is the amount of time required to implement and verify the design, as this largely determines time-to-market. Decreases in product life cycles for high technology systems have elevated the importance of achieving a fast design cycle. Unfortunately, electronic design automation (EDA) tools have failed to keep pace with the exponential growth in transistor counts. Verification of new microprocessor designs can consume 50% or more of the entire design cycle. Faced with unrealistic design schedules, designers have strong disincentives to engage in design practices that do not contribute directly to the rapid completion of the design. Extensive design documentation is an example of a generally beneficial design practice that is typically foregone in an effort to meet a schedule

By designing products that are just good enough to meet the requirements, electronic device designers have little opportunity to reuse previously developed components, or to construct components that are reusable by other designers. In other words, the design environment and the incentives that are currently in place result in little, if any, effort to evaluate the potential for reuse in the design of a new product. However, because reuse offers the potential for a low cost technique to reduce design time, it is highly desirable to implement a method that created incentives to design reusable components and to reuse existing components whenever possible. This paper presents such a method and an associated system that implements the method.

2 Overview of Approach

The problems identified above are in large part addressed by a methodology and system that encourage reuse as a design principle and reward both the design of highly reusable components and the subsequent reuse of such components in future designs. Note that, although examples are focused on electronic design, the presented methodology could be applied to the design of software systems and mixed hardware-software systems.

A team is assigned the task of designing an electronic device that includes one or more components. Each component is evaluated in terms its potential for being implemented with a previously designed component. If a decision is made to forego previously designed components, the design team is encouraged to incorporate reusability principles into the component design by a reward or compensation structure that rewards both the individual members of a team and the corporate entity which sponsored the design (be it a division, product line, etc). The reward structure also encourages teams to use existing designs wherever possible by rewarding a team that reuses an existing component. This reuse reward is in addition to the presumably shorter design time enabled by using the existing design. An innovation administrator may adjust the relative rewards for incorporating reusability into a design vs. reusing a design to state a preference for innovation in selected areas. In a mature technology, for example, the relative reward for reusing existing components vs. designing a new component may be increased while the opposite structure might be implemented in a developing area.

3 Benefits

Our approach provides the following benefits:

- *Reuse enhancement*: organizations and engineers work with the expectation of reimbursement for reuse of components.
- *Quality*: higher quality in terms of reusability (e.g., documentation) increases the chances of and expectation of residual payments and improves the overall return on investment (ROI) for the development effort.
- *Improved cross-functional cooperation*:collaboration across funding, development, and research divisions improve since it is in their common interest to produce reusable intellectual property (IP) that maximizes residuals.
- *Retention*: Engineers stay in the corporation with the expectation of residual payments and the satisfaction of multiple uses for their creations.

4 Prior Work

Several existing methods for IP reuse encouragement exist, including the following:

- Valuable design reuse approaches have been proposed in the electronic design automation (EDA) arena [1]. Unfortunately, this work has largely focused on technical aspects, and not on direct encouragement, funding and remuneration aspects [2]. Incentives for reuse are not accounted for, which hinders reuse efforts [5].
- Massive taskforces/management actions cannot fully avoid the proliferation of a number of similar but distinct designs, e.g., fixed-point units. These approaches have not addressed incentives for technologists to produce reusable designs.
- Stock options and variable pay are too diluted in quantity to produce any grip on most non-managers.

Our approach can also be seen as an innovation management technique. To our knowledge, most other approaches to managing innovation tend to focus on information management, R&D costing, or management of the process itself. However, they do not focus on direct funding of the innovation process agents [3]. While it has sometimes been recognized that rewarding innovation is important [4], little work has been aimed at a specific methodology that promotes design reuse and provides a direct reward to innovators based on design use.

5 Description of Methodology

Figure 1 shows a flow diagram of the presented method. The requirements for a device are first defined. Typically, the device includes one or more pieces referred to herein as components. The task of designing a system meeting the specified requirements is assigned to a design team by the management of a corporate entity such as a product line or a division. This entity and its management are referred to as the *sponsor* of the design.

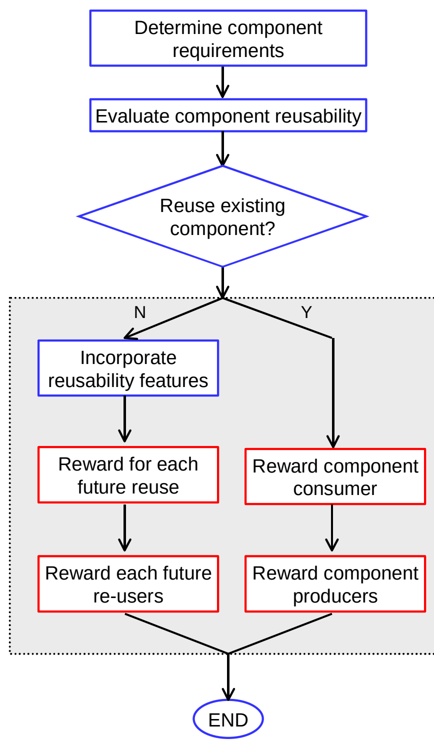

Figure 1 Reuse and quality enhancement flow.

The design team is charged with the task of designing a suitable system that meets all the specified requirements within a certain time frame. Since the success of this team is determined largely on time-to-completion, there is little incentive and may be strong disincentives to engage in design practices that might prove beneficial to some other design team within the corporation in the future. On the contrary, there typically is an incentive to generate a device in the absolutely shortest time possible. Practices that do not contribute directly to the task of completing the design quickly are scrapped entirely or substantially curtailed. For example, providing extensive documentation, accurate simulation models, and industry-standard formats are time consuming tasks that are more likely to delay the completion of a successful design than speed it up.

One obvious approach to speeding up the design cycle is to use previously existing components. However, the incentives in a conventional organization do not encourage this reuse. Using an existing component is often perceived as high risk, since the component is controlled by another organization. In our approach, the corporation encourages the design team to either design each component with an eye toward future reuse or to use a previously designed component wherever feasible.

For each component in the design, the design team initially evaluates opportunities for reusing an existing component. Evaluating reuse opportunities may include first determining if a component exists that performs the required function at the required level of performance. Assuming a functionally suitable component is available, the design team also determines whether it exists in a suitable format (e.g., is there an HDL model of the component available), evaluates the interfaces used for the component, and evaluates the documentation and level of verification completed to gauge whether the quality level of the component is sufficient for the current purpose.

After doing this evaluation, a decision is made to either use the existing component or to design a new one from scratch.

Component producer and sponsor reward

If the design team determines that it is preferable to design a new component, the team is encouraged to design their component in a manner that promotes its subsequent reuse. This may include incorporating features that exceed the minimum performance requirements, implementing standard interfaces, and documenting in detail the component design and its verification.

To encourage design teams to engage in the extra time and expense required to incorporate reusability into a project, our method includes a structure for rewarding the design team for any subsequent reuse of the component. The reward includes direct compensation to the design team members for each subsequent reuse or indirect compensation such as stock options. The compensation may be immediate or deferred over time such as by granting stock options with staggered vesting dates to encourage team member retention.

In addition to providing incentives to the IP design team, the team's sponsor is also rewarded for subsequent component reuse. While the reward to a technology sponsor could come in the form of direct compensation to the sponsoring agent's management team it may be of more value to encourage sponsors to promote reusability principles by offering sponsors compensation in the form of additional manpower. Attracting and retaining sufficient qualified personnel is a major challenge. By offering additional designers to technology sponsors, motivation is provided to encourage them to take an active role in promoting reusability.

Component consumer reward

To optimize opportunities for reuse within an organization, the method rewards not only the component producers (the design teams and technology sponsors), but also the *consumers* of reusable components. When a subsequent design team reuses a previously developed product, they may be rewarded in the same manner as the producer of the reusable component. The compensation to the consumer design team may be lower than the compensation paid to the producer to reflect the relative efforts that each party extended with respect to the particular component. Nevertheless, by incorporating direct compensation to the consumer of previously developed technology, design teams have dual incentives for thoroughly evaluating opportunities for reuse when designing a device. In addition to the time and effort that will be saved by reusing an existing component, the design team will be compensated for its reuse efforts.

To summarize, if a design team decides to reuse an existing component, both this team and the producers of the reused component are rewarded.

The design team will have incentives to become an IP producer by designing system components that may be reused in subsequent designs for years to come as well as incentives to become an IP consumer by using a previously developed design for one or more components. By managing the relative incentives for reuse v. a new design, a managing agent can influence how much reuse is undertaken. In emerging technology areas an IP reuse manager may create relatively strong incentives to design reusable components and relatively weak incentives for reuse, while in a mature field the manager may create the opposite bias.

6 Organization and funding model

Figure 2 depicts a simplified block diagram, which can be viewed as canonical, illustrating an organization where the method described above is implemented.

The organization includes at least one IP producer who is governed or supported by a funding agent or *sponsor*. This sponsor provides necessary funding and other resources, denoted by (F, R) in the figure. In addition, the organization includes at least an IP consumer and a reuse manager or *arbiter*. When the IP producer, i.e., the component design team, successfully completes a component, this component is available for reuse by the IP consumer, i.e., a team working on a different design.

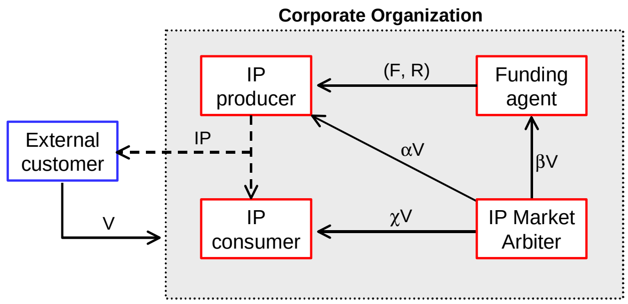

Figure 2 Organization emphasizing funding model.

The arbiter is responsible for creating the incentive structure for each reuse transaction. Specifically, the arbiter is responsible for determining the value, denoted by V, of the reusable component developed by the IP producer. In some cases, the innovation consumer is an outside customer and the value V reflects the price paid by the customer to obtain the design. In other cases, an IP consumer is internal to the organization and V is determined according to some valuation methodology.

In addition to determining valuations, the arbiter determines the rewards or compensation that each party to a reuse transaction receives. By default, the reward structure is based directly on V and can be represented by a set of functions. The *producer reward* function, denoted by Λ, is used to compute the reward provided to the IP producer for each reuse transaction involving the component:

$$P(n) = \Lambda(V(n)),$$

where $V(n)$ is the IP component value upon its nth component reuse and $P(n)$ is the reward itself. The simplest version of this method features a linear formulation where the IP producer receives a percentage of the IP value given by

$$P(n) = \Lambda(V(n)) = \alpha_n \times V(n),$$

where $\{\alpha_n, 0 \leq \alpha_n \leq 1\}$, denotes the percentage or fraction to be provided to the IP producer upon the nth component reuse. Similarly, a *sponsor reward* function, denoted by Δ, is associated with the producer's funding agent, and a *consumer reward* function, denoted by Φ, is associated with the IP consumer. As a result, using again a linear formulation, these agents receive rewards for each reuse transaction given by

$$S(n) = \Delta(V(n)) = \beta_n \times V(n)$$

$$C(n) = \Phi(V(n)) = \chi_n \times V(n)$$

where β_n and χ_n denote the sponsor and consumer fractional rewards, respectively. Innovation can be encouraged by making α_n, β_n and χ_n monotonic decreasing functions of n. The first (intended) use of the component is not rewarded, i.e., $\alpha_0 = \beta_0 = \chi_0 = 0$. The condition $\alpha_n + \beta_n + \chi_n = 1$ is not necessary, due to policy factors that include profit management and cost recovery funding for the IP arbiter organization.

The compensation awarded for each reuse transaction may also be determined according to a non-linear formulation. For example, an IP consumer may receive a fixed sum (i.e., C is a constant) instead of a percentage of the valuation. Recall that a funding agent may also receive alternative forms of compensation such as increased head count or budget.

Without loss of generality, the total reward received by the IP producer upon n reuse instances is given by

$$P_T = \sum_{i=1}^{n} P(i) = \sum_{i=1}^{n} [\alpha_i \times V(i)]$$

This reward has to be traded off against the *hardening cost*, i.e., the cost of incorporating reusability features for each reuse instance. Let $H(n)$ be the marginal hardening cost incurred to enable the nth reuse instance. The net income for the IP producer, denoted by N_T, can then be expressed as

$$N_T = \sum_{i=1}^{n} [\alpha_i \times V(i) - H(i)] - H(0),$$

where $H(0)$ is given by the initial expense incurred with an eye toward future component reuse. Therefore, even without accounting for sponsorship income, the IP producer may achieve a "break-even" point after a certain number of reuse instances. Achieving that breakpoint allows the IP innovator more independence from the sponsor and/or the opportunity to grow as a reward for sustained innovation and corporate impact.

Accounting for the valuation of the initial funding and resource sponsorship, denoted by $P(F,R)$, the total net income including sponsorship, denoted by N_{TR}, is given by

$$N_{TR} = P(F,R) - H(0) + \sum_{i=1}^{n} [\alpha_i \times V(i) - H(i)]$$

It can be shown that, for the corporation as a whole, our method can result in overall net revenue increases for a given design since it (1) increases the market value of the design by accelerating its completion, (2) reduces the cost of completing the design, and/or (3) encourages component quality.

7 Reuse And Quality Enhancement System

Figure 3 shows a block diagram describing a simplified top-level architecture for a system that implements our method. The system depicted here includes an *IP consumer subsystem* that works in conjunction with an *IP producer subsystem*, an *IP sponsor subsystem*, and an *valuation and reward management engine* to coordinate and facilitate reuse transactions where a design team reuses a component previously designed by the IP producer. Although a number of producer, consumer, and sponsor subsystems may exist, only one copy of each is represented here for simplicity.

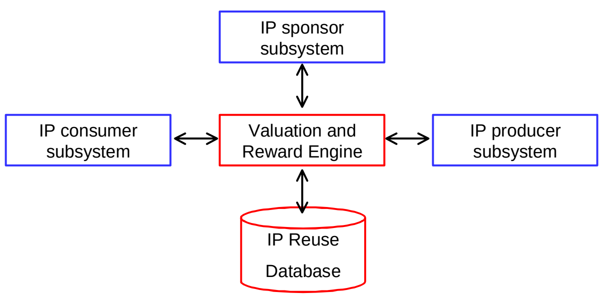

Figure 3 Architecture for reuse enhancement system

Assuming a distributed approach, the subsystems in this architecture have the following characteristics:

- The IP producer system includes information about the status of components in progress, the level of verification and testing, the formats in which the components exist, and the expected completion date of designs-in-progress.
- The IP sponsor system includes higher-level information for each component in progress. This information may include the resources (i.e., man-hours and/or dollars) invested in a design, and the number of reuse transactions contemplated or completed for each design.
- The IP consumer system includes reuse transaction information such as the effective date of a reuse transaction, the identity of the reusing design team, and pointers to the reused design and its corresponding design team and sponsor.
- The valuation and reward manager is responsible for collecting the information provided by each of the component systems and storing the information in a (potentially distributed) database. From this information, the engine generates compensation transactions that accompany each reuse transaction.

In an alternative, less distributed configuration, the reward engine not only tracks and generates reuse transactions and the corresponding incentive payments to be made, but also participates and facilitates the reuse decision itself. To enable this configuration, the producer subsystem may include technical information concerning the function of components, the architecture and details of their interfaces, and the identity of the principal designers and whether or not those designers are still within organization. Similarly the IP consumer subsystem may include analogous information for each of its designs. Note that, although the depicted illustration indicates a single system with a plurality of components, the system may be implemented in a distributed fashion.

8 Example

An example is presented here that illustrates the typical effect of our reuse enhancement method on an IP-producing corporation (the example is based on estimates and does not refer to any IBM project). The component to be reused is a serial communication link block, initially intended for use in an embedded processor design.

Table 1 shows the assumptions contemplated in the example. Two cases are considered, using different reward parameters for the IP producer. While case 1 has a constant IP producer reward parameter of α=10%, the parameter is increased to 15% for Case 2.

Parameter	Value (case 1)	Value (case2)
α	10 %	15 %
β	10 %	10 %
χ	5 %	5 %

Table 1. Key example parameters.

Based on these assumptions and applying our method, Figure 4 shows the cumulative net revenue for the IP producer design team, normalized to its initial development expense. To emphasize the power of our approach, the funding and resources initially provided by the sponsor are not included in the net revenue. The horizontal axis represents the number of reuse project instances, where "0" denotes the initial intended use for the design.

The component is initially designed, including only features that are necessary for its first use. This initial design thus provides only negative revenue for the IP producer in both cases.

After its first intended use, the component is adapted to its second use, a storage application. Reusability features are incorporated to "harden" the component, including documented, synthesizable HDL code, portable timing information and libraries. Despite the reuse reward received, the cumulative revenue is still negative in both cases, due to initial development costs and one-time hardening costs. Case 2 has a slightly higher revenue level due to its higher producer reward parameter value.

The next reuse, a media processor-based design, entails less hardening work. Only I/O interface issues need to be addressed for the application. Revenue loss thereby drops significantly. However, while Case 1 remains in negative territory, Case 2 has achieved a positive-revenue break point *before* accounting for the funding and resources provided by the sponsoring organization. This result is not only due to the higher direct reward in Case 2. The reused IP also has a higher market valuation in Case 2, because the extra reuse rewards allow more resources for IP generation and hardening, thereby accelerating component availability for reuse.

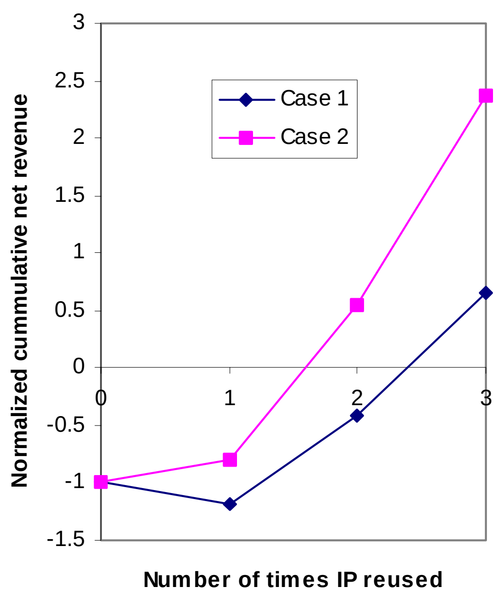

Figure 4 IP producer normalized cumulative revenue.

Finally, the last reuse is performed on a internal broadband processor-based system-on-a-chip. Practically no hardening cost is incurred and thus Case 1 achieves a positive cumulative net revenue.

The example indicates that it is important to set the reward rates properly to achieve the right behavior. The trade-off for higher reward rates is (1) the raise in immediate reward cost and (2) the potential reduction in the creation of innovative designs.

Data can also be presented that shows the behavior of the overall corporation net revenue for the component. For this example, the resulting total corporate net revenue for the component is 3.5% higher in Case 2 when compared to Case 1. Again, higher net revenue is possible despite increased reward cost, because of the higher market value that the component achieves. Finally, when compared with an approach without reuse and rewards, net revenue for the component is 15% higher in Case 1.

9 Conclusions

An IP reuse enhancement method and system has been presented that encourages component reuse in system design by (1) evaluating and responding to the opportunity to use previous designs, (2) developing system components with regard to future, targeted reuse, (3) rewarding the IP component innovator, and (4) rewarding the IP consumer.

Further work includes the development of the infrastructure that supports this method, including a valuation and reward management engine, and techniques to optimally determine reward rates.

10 References

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